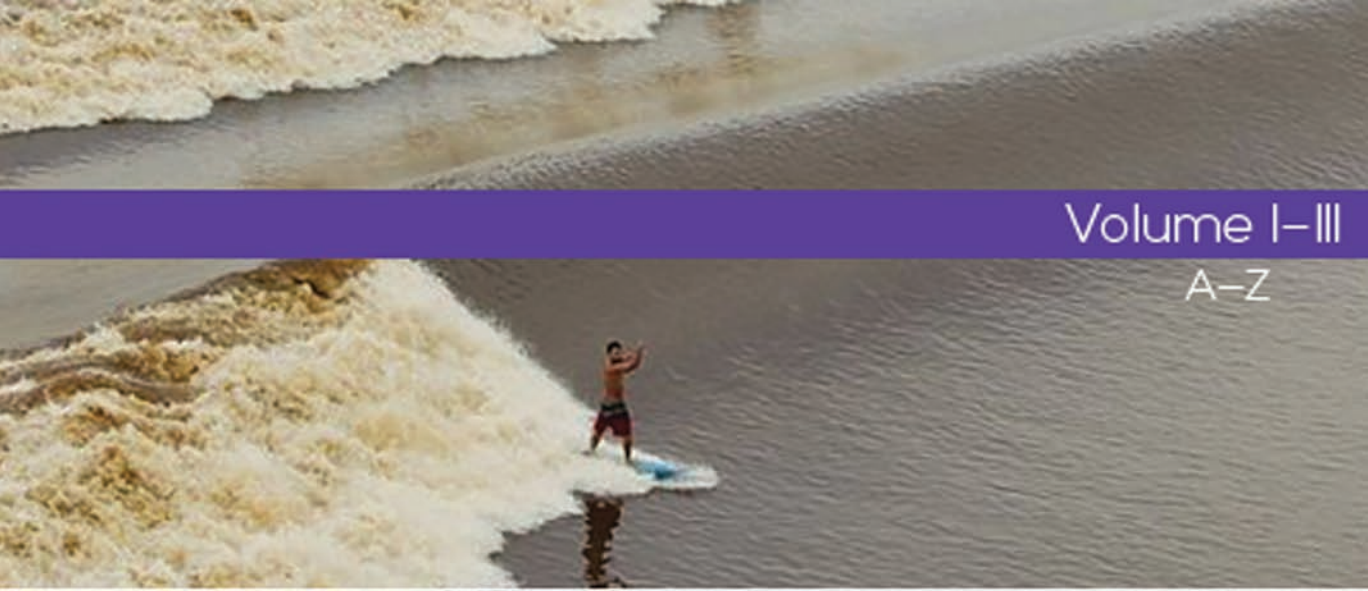




Volume I–III
A–Z

Illustrated Encyclopedia of **Applied and Engineering Physics**

Robert Splinter, PhD



CRC Press
Taylor & Francis Group

Illustrated Encyclopedia of
**Applied and
Engineering Physics**

Volume I
A–G



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Preface

The purpose of this *encyclopedia* is to provide a single, concise reference that contains terms and expressions used in the study, practice, and applications of physical sciences. The reader will be able to quickly identify critical information about professional jargon, important people, and events. This encyclopedia gives self-contained definitions with essentials regarding the technical terms and their usages and information about important people in the following areas of physics:

- Acoustics
- Astronomy/astrophysics
- Atomic physics
- Biomedical physics
- Chemical physics
- Computational physics
- Condensed matter
- Dynamics
- Electromagnetism
- Electronics
- Energy
- Engineering
- Fluid dynamics
- General
- Geophysics
- High-energy physics
- Imaging
- Instrumentation
- Materials sciences
- Mechanics
- Meteorology
- Nanotechnology
- Nuclear physics
- Optics
- Quantum physics
- Relativistic physics
- Rheology
- Sensing
- Signal processing
- Solid-state physics
- Theoretical physics
- Thermodynamics
- Ultrafast phenomena

This reference differs from the standard dictionaries in its inclusion of numerous illustrations, including photographs, micrographs, diagrams, graphs, and tables, which support the textual definitions and draw the reader into the explanation to enhance didactic value. Together, these over 2500 entries will educate the reader about the current practice of physics and its applications in biomedicine, materials sciences, chemical engineering, electrical engineering, mechanical engineering, geology, astronomy, meteorology, and energy.

It is envisioned that novices and trainees, in addition to seasoned professionals, will find this resource useful, both for sustained reading and for taking a dip into the topics periodically. The contents are also designed to help the professionals who are new to a work environment and recently enrolled students who need to become more familiar with terminology and nuances relevant to certain research and applications. Moreover, it will assist in understanding the primary literature as well as technical reports and proposals. Finally, any student from the high school to graduate levels should be able to benefit from the broad and applied emphasis of this concise encyclopedia, which may support undergraduate courses in applied sciences for nonscience majors.

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Robert Splinter, PhD, obtained his master of science degree in applied physics from the Eindhoven University of Technology, Eindhoven, the Netherlands, and his PhD from the VU University of Amsterdam. Dr. Splinter built his career as a scientist and technology manager in biomedical engineering. His work is dedicated to resolving issues in device development with a particular focus on medicine and biology through the development of novel diagnostic techniques and treatment methods using all multidisciplinary aspects of engineering and applied physics.

He cofounded several companies in biomedical engineering and worked for several established metrology and medical device companies. In addition, Dr. Splinter worked in clinical settings, prototyping, and validating devices using the full practical and theoretical knowledge of physics, engineering, electrical engineering, chemistry, and biology. He is an associate professor (Adj.) in the Department of Physics at the University of North Carolina at Charlotte.



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Abbe, Ernst Karl (1840–1905)

[general, imaging, optics] A physicist from Germany (Prussian Empire) who worked for CARL ZEISS (1816–1888) in microscopy development, providing systematic advancement in LENS design and quality of the IMAGE formation based on his mathematical formulation of light REFRACTION. Additional efforts in telescopic and PHOTOGRAPHY equipment made considerable qualitative improvements. Ernst Abbe, as the heir of the will of Carl Zeiss, was placed in charge of the factory upon Zeiss' death in 1888. Abbe was also the cofounder of the GLASS factory Schott in Jena, Germany. Abbe formally introduced the concept of NUMERICAL APERTURE (see [Figure A.1](#)).



Figure A.1 Ernst Karl Abbe (1840–1905), a scientist from Germany. (Courtesy of Emil Tesch, taken around 1905.)

Abbe condition

[general, instrumentation, optics] (syn.: resolution) {use: imaging} The ability to distinguish two neighboring points, the RESOLVING POWER between these two points based on the angular resolution of the instrument (EYE, MICROSCOPE). This concept was independently described by both the German physicist ERNST KARL ABBE (1840–1905), while working for CARL ZEISS (1816–1888) in 1878, and the English physicist JOHN WILLIAM STRUT, THE 3RD BARON RAYLEIGH (1842–1919). When two objects are projecting their images through the same APERTURE, each object will generate its own diffraction pattern: AIRY DISK. The Airy disk of object 1: image A will overlap with the Airy disk of object 2: image B. Under the condition that the first maximum from the center of image A is adjacent to the first maximum of image B, and not overlapping, the two IMAGES can be separated or resolved. The RESOLUTION is a direct function of the WAVELENGTH λ of the

ELECTROMAGNETIC RADIATION used for imaging. The RAYLEIGH CRITERION for a circular aperture (e.g., LENS) will require corrections for the separation between the edges, and results in the fact that the ANGLE ω that can separate two objects in respect to the aperture of the viewing device (pupil, lens, and aperture, as in a CAMERA OBSCURA) needs to satisfy the following angular definition that defines the two points that can be resolved: $\omega = \lambda / n \sin(\omega) \equiv 1.22 \lambda / D$, in AIR at 550 nm for HUMAN EYE, where D is the diameter of the opening or the diameter of the aperture and ω is the half-angle of the cone of rays emitted from the opening and $n \sin(\omega) = \text{NA}$ is the NUMERICAL APERTURE (NA). A bird of prey has a very high resolution due to the fact that the eye only has a relatively small angle of VISION resulting from a densely packed RETINAL RODS configuration and a large pupil diameter, approximately $\omega = 0.18$ arcmin compared to the FOVEA of the human eye with both CONES and RODS: $\omega = 0.30$ arcmin. In addition, some birds of prey have a double foveae that allows for simultaneous high-resolution (this is in particular called the *convexiculate fovea*) and low-resolution vision (see REFRACTION; also see RAYLEIGH CRITERION) (see Figure A.2).

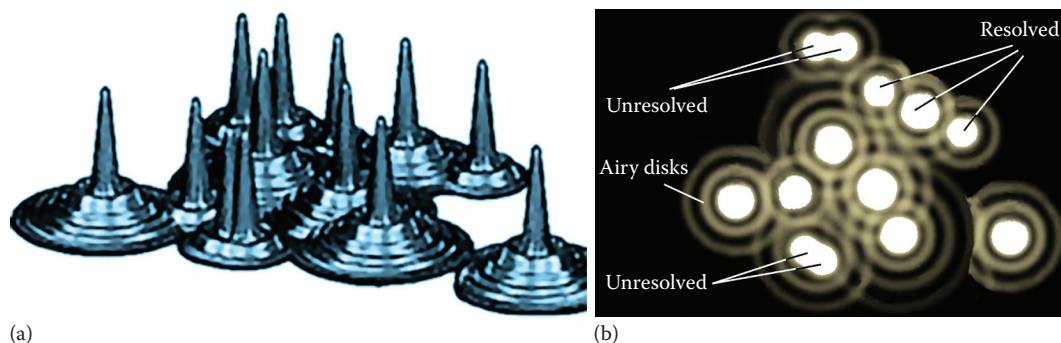


Figure A.2 Abbe criterion: (a) Airy disks created by diffraction originating from the edges of an aperture for a number of sources, allowing only sources that are separated by the Abbe criterion to be distinguished separately and (b) diffraction pattern with minima and maxima.

Abel, John Jacob (1857–1938)

[biomedical, chemical] A professor of pharmacology from the United States who invented and prototyped the first DIALYSIS machine in 1912; the process was then called vividiffusion and was intended to prepare the treatment of patients with kidney disease. The first human applications were by GEORG HAAS (1886–1971) in 1924 in Germany. Abel also discovered the amino acids as constituents of BLOOD (see Figure A.3).

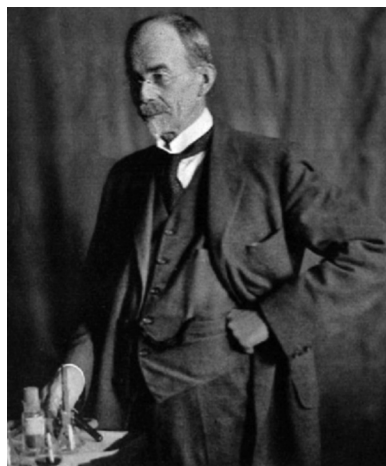


Figure A.3 John Jacob Abel (1857–1938) from the United States. (Courtesy of Doris Ulmann.)

Aberration, chromatic

[optics] A LENS (i.e., TRANSPARENT shape or curved MIRROR) may have different focal points for different WAVELENGTHS. The INDEX OF REFRACTION of most transparent solids is a function of the wavelength; hence the REFRACTION will change across the SPECTRUM. A PRISM produces a RAINBOW due to the fact that the optical material (crown glass, flint glass, plastic, etc.) refracts at each surface with an ANGLE specific for the incident wavelength. Transparent materials under stress also generate density variations resulting in a specific localized index of refraction, which in turn results in stress-induced COLOR patterns under WHITE LIGHT illumination, allowing this phenomenon to be used for quality control purposes (see [Figure A.4](#)).

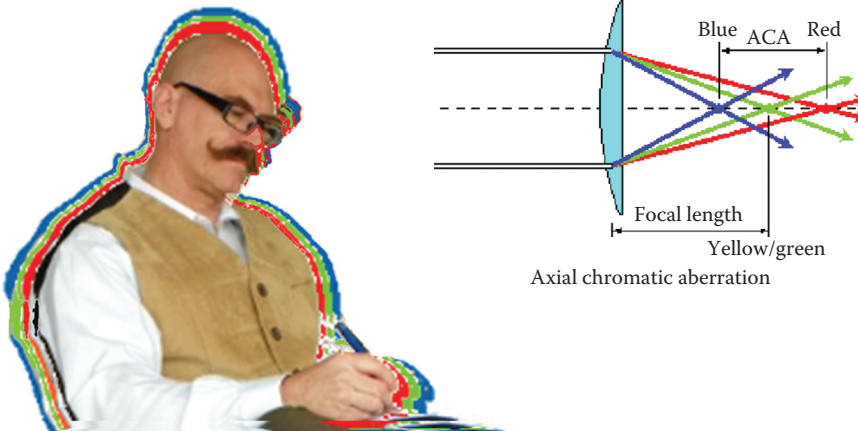


Figure A.4 Graphic illustration of chromatic aberration.

Aberration, spherical

[optics] Linear LIGHT ray distortion resulting from imperfections in the LENS or MIRROR design or imperfections in the lens material (mirror coating) with an inhomogeneous INDEX OF REFRACTION across the volume of the lens. The edges of a lens (i.e., curved mirror or transparent shape) may focus at a different location than the rays passing close to the OPTICAL AXIS (see [Figure A.5](#)).



Figure A.5 Graphic illustration of spherical aberration: (a) undistorted picture of a buzzard chick and (b) distorted view obtained with badly shaped and uncorrected lenses illustrating the spherical aberration resulting from inferior optical instruments.

A-bomb

[atomic, nuclear] *See* ATOMIC BOMB.

Absolute energy

[thermodynamics] Internal ENERGY under conditions of SPECIAL RELATIVITY, such as nuclear mechanics and the STATE OF A SYSTEM. When the state of a system $\mathcal{A}$ changes from one configuration (“1”) to another (“2”), the energy provided as WORK as a function of position $\mathcal{Z}$ is initially written as: $W_{12}^{\mathcal{A}} = Mg(\mathcal{Z}_2 - \mathcal{Z}_1)$. By including the special relativity conditions when considering the nuclear interactions, this becomes: $W_{12}^{\mathcal{A}} = Mc^2(e^{g\mathcal{Z}_2/c^2} - e^{g\mathcal{Z}_1/c^2})$, where c is the speed of light in VACUUM and M is the MASS at $\mathcal{Z} = 0$. The energy E of the system $\mathcal{A}$ with movement at velocity v and MOMENTUM “ $\vec{p}$ ” is compliant with $M\sqrt{(E^2 - |\vec{p}|^2 c^2)} = mc^2$, where m is the mass of the system. This translates into an energy equation for the two-state system, assuming one GROUND STATE, with momentum $\vec{p} = 0$ by definition, and both states are otherwise equal in energy. The energy for the two-state system can now be written as $E_1 = E_2 = m_2 c^2 \sqrt{1 + (|\vec{p}_2|^2 / m_2^2 c^2)}$. For a system (PARTICLE, MOLECULE, ATOM, or [electric/magnetic/EM] FIELD without external force), the ground-state mass can be derived from MASS-SPECTROSCOPY measurements and is defined as m_g^{free} . Expanding the process for a multitude of states all in ground state ($\mathcal{Z}_g$), this denotes the total energy of the free system F , with n states and r types of ELEMENTS or constituents as: $E_g^F = \sum_{i=1}^r n_i (m_g^{\text{free}})_i c^2$, where $(m_g^{\text{free}})_i$ is the ground-state mass for the i th free constituent under special relativistic conditions. Now the absolute energy can be derived with the help of the following equation: $E_0^{\mathcal{A}} = \sum_{i=1}^r n_i (m_g^{\text{free}})_i c^2 + V_0(n, \beta, \text{internal forces})$, describing the absolute energy values of each of the respective states, and $V_0(n, \beta, \text{internal forces})$ is the configuration of external ($\beta_1, \beta_2, \beta_3, \dots, \beta_j$) and internal forces. These forces can be turned on or off based on the relativistic conditions.

Absolute entropy

[thermodynamics] $S(\mathcal{A}) = \int_0^{\mathcal{A}} dQ/T$ (*see* ENTROPY), which is undefined for the ABSOLUTE ZERO temperature. The inclusion of a constant (ENTROPY CONSTANT OF A GAS) compensates to define the entropy of every system at absolute zero to equate to zero. Stated in its original form by WALTHER HERMANN NERNST, Nernst’s “heat theorem” formulates that the entropy equation is applied only to condensed systems; however, it was later proven to hold true for gaseous systems as well.

Absolute gravitational acceleration (g_0)

[astrophysics, general] GRAVITATIONAL ACCELERATION as the result of the attraction between two bodies resulting from the mass of one primary body (M) calculated at a point with respect to the square of radius from the core (R), with no other forces acting (e.g., no rotation: CENTRIPETAL FORCE): $g_0 = GM/R^2$ (*see* Figure A.6).



Figure A.6 Illustration how gravitational acceleration will result in increasing velocity on a downhill run for a roller-coaster ride.

Absolute pressure (P)

[fluid dynamics, general] PRESSURE measured against absolute VACUUM, in contrast to ATMOSPHERIC PRESSURE, units (TORR) (see [Figure A.7](#)).

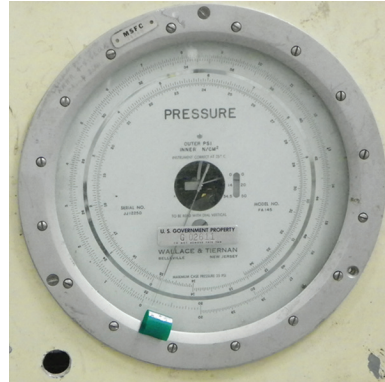


Figure A.7 A pressure gauge providing absolute pressure value. The mirror annulus allows for accurate determination when viewing the position of the needle covering its own image.

Absolute simultaneity

[computational, general] A virtual concept proposed under special relativistic conditions describing the apparent correlation between multiple inertial systems outlining a frame of reference. Absolute simultaneity entails that the observations made by observers of two simultaneous event observed in one reference frame midway in space between the two events would also be experienced by observers in another inertial system as simultaneous. This, in fact, is not necessarily true, primarily because of the specific definition of the boundary conditions of each reference frame in space and time. The discrepancy results from the relativistic concept of TIME DILATION, where time is relative to the observer's inertial frame of reference and consequently DISTANCE is subjected to the boundary conditions of the reference frame of the observer (see [Figure A.8](#)).

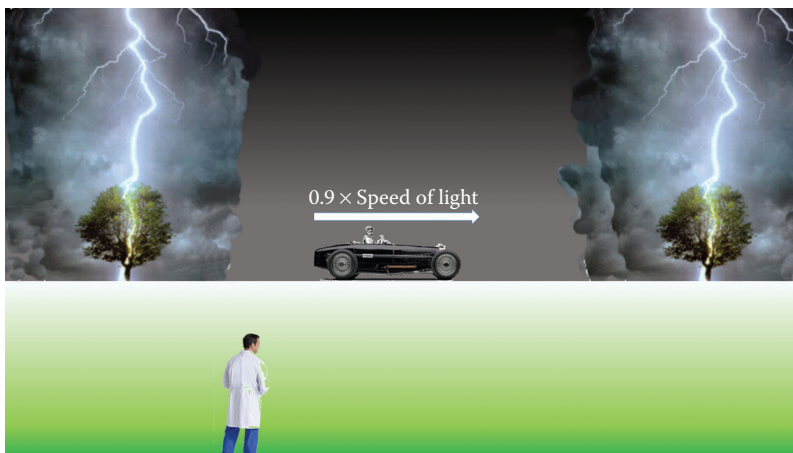


Figure A.8 The principle of simultaneity. Two events that occur simultaneously in two separate locations may not be observed as equivalent between two observers in separate frame of reference, one reference frame traveling close to the speed of light.

Absolute streamline density ($\rho(u)$)

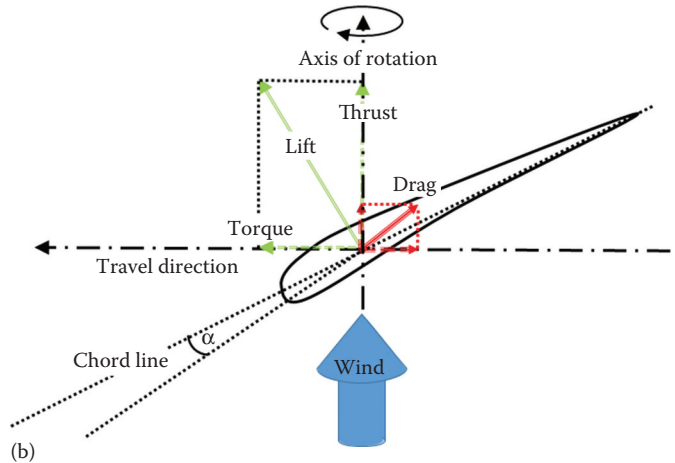
[imaging] Concept in imaging derived from seed point analysis revealing “fiber orientation” in a POLYMER or biological medium composed of a seemingly fibrous structure.

Absolute streamlines

[fluid dynamics] Concept used in turbines and generators indicating the direction and FLOW velocity of a FLUID IN MOTION, the vector length or number of lines indicates the velocity. The absolute streamline points in the direction of LIFT for a turbine blade. The BERNOULLI'S EQUATION for the absolute streamline in a TURBINE is given by $(P_2 - P_1)/\gamma = \left[(V_1^2 - V_2^2)/2g \right] - \left[u(V_{\theta 1} - V_{\theta 2})/g \right]$, where $u(V_{\theta 1} - V_{\theta 2})/g$ is Euler's turbine equation (see Figure A.9).



(a)



(b)

Figure A.9 Streamlines illustrate the local direction and magnitude of fluid flow in either a tube or around an object. The density of the streamlines provides a visual reference to the magnitude (as vector indication): (a) visual display of streamlines generated by water-vapor jets at a distance from the object subjected to flow. The flow around the Mercedes CLA automobile illustrates the lowest coefficient of flow friction for a production automobile to this date ($C_d = 0.23$). (Courtesy of Daimler AG.) The stream lines of flow provide the information that can be used to calculate lift, thrust drag, and torque resulting from the motion of the aerofoil of a wind generator blade, respectively, a boat propeller, rotating in a viscous fluid. The reported first use of wind-powered water well pumps dates back to the Persian Empire, 900 AD. (b) Diagram of forces acting on a horizontal axis wind turbine (HAWT); torque and thrust on a wind-generator blade section under the influence of streamlines. The streamlines are the vector resultants from the wind direction and magnitude and the respective travel direction of the propeller. The streamlines for a rotating propeller are continually varying and are also modified by the flow-induced vortices.

(Continued)

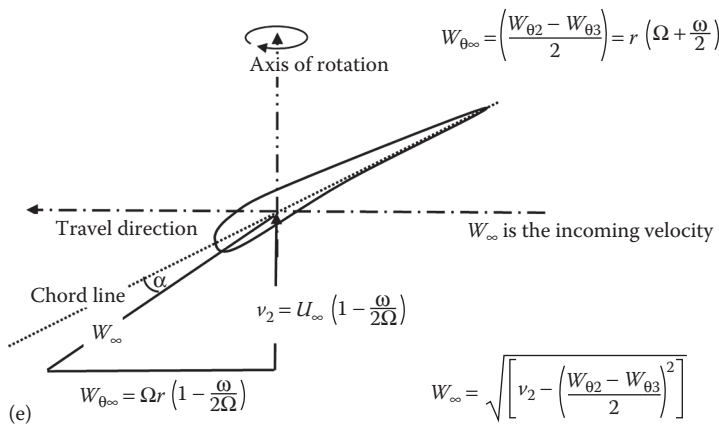
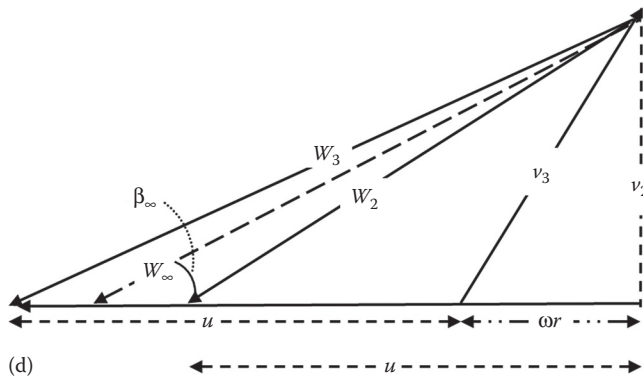
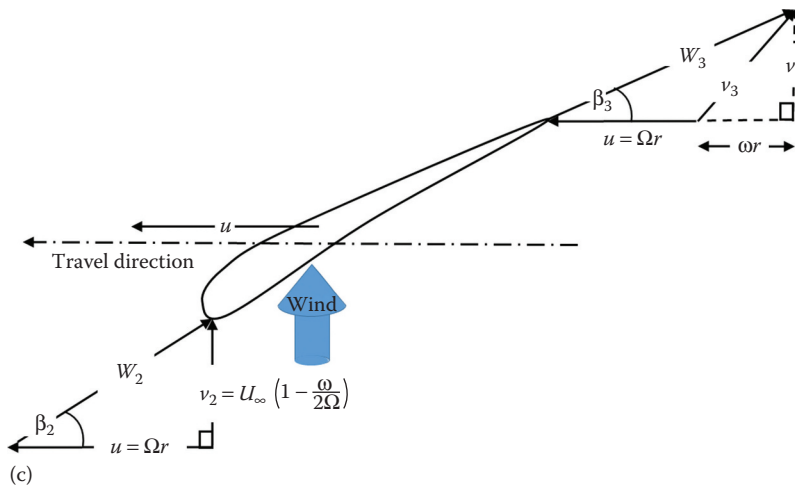


Figure A.9 (Continued) Streamlines illustrate the local direction and magnitude of fluid flow in either a tube or around an object. The density of the streamlines provides a visual reference to the magnitude (as vector indication): (c) diagram of velocity vectors with respect to the streamlines on the inlet and outlet side of a propeller blade. The angular velocity of the propeller is indicated by Ω with respect to the radial distance from the axis r , with the relative flow velocity as a function of angle ω . (d) Trigonometry of the velocity vectors outlined for the streamlines in (b) and (e) derived effective incoming fluid stream velocity on the rotating blade.

Absolute temperature

[thermodynamics] Temperature based on the KELVIN SCALE with the lower limit set as the point that cannot exchange any heat. Because the CARNOT CYCLE is not ideal and violates the SECOND LAW OF THERMODYNAMICS, not all heat dissipation is converted into work. The theoretical implication is that the ABSOLUTE ZERO can never be reached for a functional volume of medium.

Absolute temperature (T)

[general, thermodynamics] The absolute temperature is defined as the inverse of the partial derivative of the ENTROPY (S) of a system with respect to the ENERGY (E) of the system as a function of state defined by the amount of the constituent n —the system may consist of r constituents ($n_i, i = 1, 2, \dots, r$), and environmental parameters: β^* common to the many assorted states of the system, which is composed of, for instance, volume, pressure, and more, and is formulated as $T = \left[\partial S(E) / \partial E \right]_{n, \beta^*}^{-1} = (\partial E / \partial S)_{n, \beta^*}$. The temperature is the result of kinetic energy from the MOLECULAR MOTION, which can be split into four categories: vibrational, scissor action, rotation, and potential energy. The temperature (T) results from solving the equation $(1/2)mv_{av}^2 = (3/2)kT$, where v_{av} is the average VELOCITY of the atoms and molecules in the medium with mass m , and k is the BOLTZMANN CONSTANT. Absolute temperature is expressed in KELVIN (K).

Absolute temperature scale

[general, thermodynamics] Measure of temperature proposed by WILLIAM THOMSON (1824–1907), *also* LORD RAYLEIGH, in 1848: the scale is based on the thermodynamic concepts of the CARNOT ENGINE, where the high temperature (T_H) ENERGY intake (Q_H) compared to the lower temperature (T_L) exhaust energy (Q_L) is correlated as $Q_L / Q_H = T_L / T_H$. The Carnot engine is assumed to operate from the upper temperature of boiling water and the lower temperature at FREEZING water, the scale is based on subdividing the CARNOT CYCLE in 100 subunits, each performing an equal amount of work (i.e., equal area) with the isotherms separating the cycles defined as 1 K apart. The scale is in perfect agreement with that of the CONSTANT-VOLUME GAS THERMOMETER, primarily because a PERFECT GAS will obey the Carnot equation. The only flaw in the reasoning is that not all the energy difference in the Carnot cycle is converted into work (ΔW) (see Figure A.10).

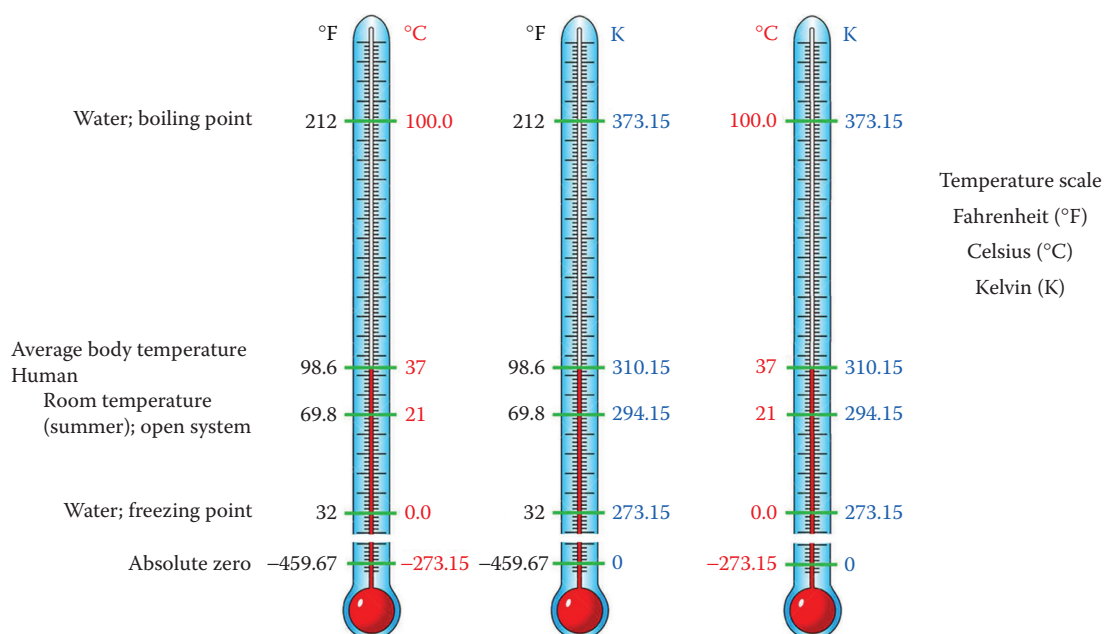


Figure A.10 Thermometers representing the different scales and the reference to absolute zero.

Absolute viscosity (μ)

[biomedical, fluid dynamics] The DYNAMIC VISCOSITY of a LIQUID, in contrast to the KINEMATIC VISCOSITY. It is a measure of internal RESISTANCE of a liquid. The absolute VISCOSITY is determined from the tangential force per unit area (SHEAR STRESS: τ) required to maintain a constant VELOCITY in the x -direction when applied on a plane that is at a fixed DISTANCE (in the y -direction) from a stationary parallel surface separated by the liquid of interest. Using a NEWTONIAN LIQUID, the shear stress in the liquid as a function of distance to the plane under LAMINAR FLOW conditions is given as $\tau = \mu(dx/dy)$ (Poise: p or Ns/m² or Pa*s or kg/ms) (see Figure A.11).

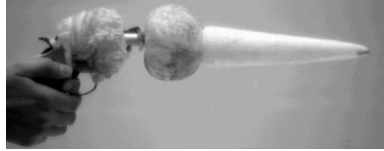


Figure A.11 Viscous friction from a dense fluid. The kinematic viscosity endured by this bullet fired into water generates a shear stress at the interface creating a turbulent boundary layer. The shear stress additionally slows down the bullet, so that it may be captured with moderate high-speed photography.

Absolute zero

[general] The energetic point where all MOLECULAR MOTION has ceased and the temperature as defined has reduced to zero (i.e., entropy = 0). This temperature point equates to -273.15°C or -459.67°F . The principle uses the gas thermometer (based on GALILEO GALILEI's (1564–1642) THERMOSCOPE concept, c. 1592) and a statement by JOHANN HEINRICH LAMBERT (1728–1777) (in 1779) that the lowest temperature should equate to the absence of the exchange of heat; as the temperature approaches zero theoretically, the volume of the GAS in the THERMOMETER will also approach zero. This hypothetical limit can never be reached universally due to conflict with the SECOND LAW OF THERMODYNAMICS; however, this condition could occur in the center of a larger medium while excluding direct contact with the containment walls.

Absorbed dose (D_c)

[biomedical, energy] In RADIATION THERAPY, this indicates the potential for the biological effect caused by radiation delivered and absorbed at locations $\vec{r}$ in the direction $\vec{s}$ with respect to the surface of an absorbing volume. The absorbed dose (D_c) is a direct function of the fluence $\vec{L}(\vec{r}, \vec{s})$ of photons with ENERGY (E) with respect to the absorbed energy per unit MASS (m) expressed by the MASS ENERGY absorption coefficient (μ_{en}/ρ), also referred to as *mass-energy attenuation*: μ_{en}/ρ , $D_c = (\Delta E_{\text{absorbed}}/m) = [\vec{L}(r, \theta, \phi) \cdot \vec{r}] E(\mu_{\text{en}}/\rho)$. The absorbed dose is different from the KERMA (also “collision Kerma,” K_c) because the latter describes the energy transferred between the radiation applied and the medium the radiation is migrating through, not the

absorbed radiation. Absorbed dose is expressed in Gray: $[Gy] = 1 \text{ J/kg} = 100 \text{ rad}$. Absorbed dose is different from “radiation exposure” (see Figure A.12).

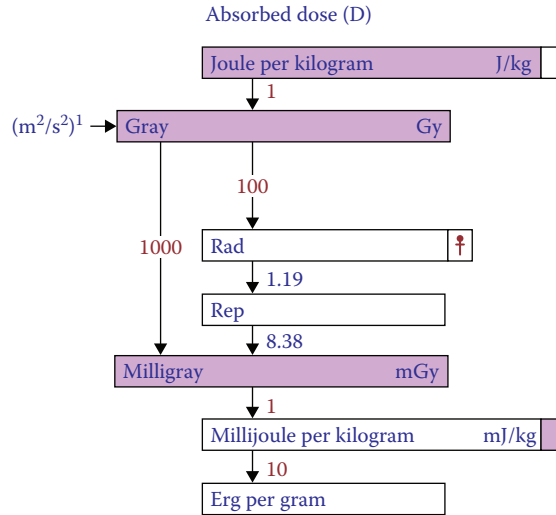


Figure A.12 Absorbed radiation dose equivalent table. Does not provide indication of magnitude for biological or chemical effect.

Absorptance (μ^*)

[atomic, chemical] Ratio of the “absorbed” RADIANT ENERGY ($\Psi_0 - \Psi(\xi)$), after traversing a thickness (d) in an arbitrary direction within a medium, to the incident radiant energy (Ψ_0) expressed as $[\Psi_0 - \Psi(\xi)]/\Psi_0 = \mu^*$, in contrast to ABSORPTION, which yields the ABSORPTION COEFFICIENT (μ_a). For a BLACK BODY, the ABSORPTANCE equals unity ($\mu^* = 1$).

Absorption

[fluid dynamics, general, nuclear, optics] The conversion of ENERGY from an external source during interaction on an atomic level. The electronic interaction can be described by the LORENTZIAN ELECTRON OSCILLATOR MODEL. Pertaining to the loss of one or more modalities (e.g., mass), attributes (e.g., gaseous absorption = chemical), or phenomena (e.g., ELECTROMAGNETIC RADIATION). (1) Conversion of one form of energy (primarily ELECTROMAGNETIC energy) into another form of energy when interacting with a medium primarily THERMAL ENERGY (i.e., DISSIPATIVE ABSORPTION); (2) incorporation of one substance/constituent into another source of MATTER; and (3) diminished AMPLITUDE as a result of RESISTANCE, for example, oscillating string (GUITAR, PIANO, etc.).

Absorption, by solids

[acoustics, atomic, mechanics, optics, solid-state] When waves or chemicals pass through a solid they are reduced in MAGNITUDE, either by formation of bonds (chemicals) or by dissipation into THERMAL ENERGY or other forms of energy, such as ELECTRICITY. An acoustic wave is made audible when absorbed by solid, where ELECTROMAGNETIC RADIATION can produce electricity (i.e., PHOTOELECTRIC EFFECT) or temperature (i.e., VIBRATION).

Absorption, of gamma rays

[atomic] High-energy PHOTON absorption in the nuclear core of an ATOM.

Absorption, of radiation, heat

[atomic] Conversion of ELECTROMAGNETIC ENERGY to THERMAL ENERGY. The dispersed absorption (e.g., BEER–LAMBERT LAW) creates thermal gradient resulting in the FLOW of energy from higher to lower temperature (i.e., heat).

Absorption, of X-rays

[atomic] High-energy PHOTON absorption in the atomic electron transitions (as described in the BOHR ATOM model).

Absorption, optical by gases

[atomic] Molecular or atomic absorption of ELECTROMAGNETIC RADIATION resulting in element-specific black lines in the transmitted spectrum that can be used for identification of the constituents of the GAS. Generally, the pressure of the gas has to be relatively low to be able to accurately identify the characteristic lines (see [Figure A.13](#)).

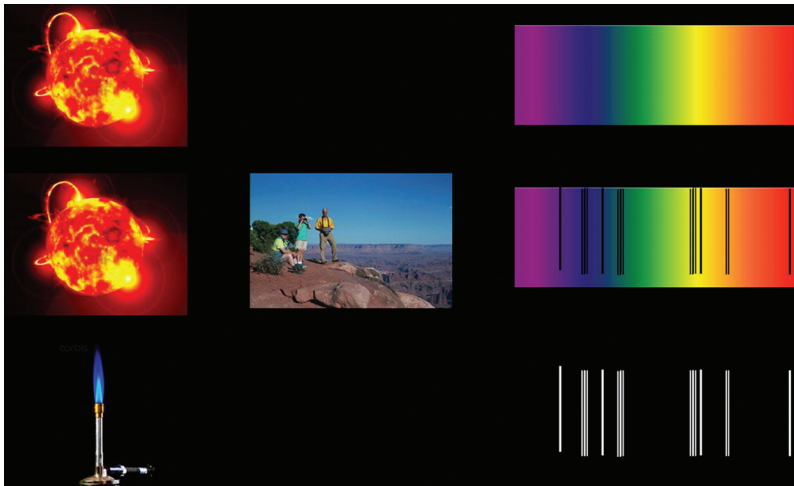


Figure A.13 Spectral profile of the absorption of sunlight in transmission through atmospheric nitrogen (~70% of total gas volume), in comparison to the spectral emission of the heated nitrogen gas (bottom right).

Absorption coefficient ($\propto$)

[general, nuclear, optics, solid-state] The proportional DECAY equivalence of a scalar quantity (ΔN) with respect to the original quantity (N_0) and the path length traveled (ξ) in a medium that reduces the original quantity due to conversion of ENERGY or state $\Delta N = -\propto N_0 \xi$, with SOLUTION $N = N_0 e^{-\alpha \xi}$, which is known as the BOUGUER LAW or Beer–Lambert law (see EINSTEIN COEFFICIENT and ATTENUATION COEFFICIENT).

Absorption coefficient, linear

[atomic] See ABSORPTION COEFFICIENT. In one direction, as expressed by α in: $-dI/I = \alpha * d\xi$.

Absorption coefficient, mass (μ/ρ)

[atomic, nuclear, solid-state] Attenuation (μ) of ELECTROMAGNETIC RADIATION due to COMPTON EFFECT, PHOTOELECTRIC EFFECT, and PAIR PRODUCTION per unit DENSITY (ρ) of atoms in an absorbing volume of material. This attenuation process in the $\hat{z}$ -direction still obeys the BEER–LAMBERT LAW, and is written as $I_{\hat{z}} = I_0 e^{-(\mu/\rho)\rho\hat{z}} = I_0 e^{-\mu_m m_a}$.

Absorption coefficient, X-ray

[atomic, nuclear] The element-specific absorption is directly related to the orbital ENERGY levels of electrons and nucleons. In general, lower energy X-RAY photons will have a higher PROBABILITY of interaction on an atomic level. The values for virtually all ELEMENTS and various chemical combination are tabulated in dedicated reference books. Because the absorption of X-ray RADIATION is an energy phenomenon, the energy of the radiation needs to be considered when calculating the radiant intensity: $I = \int_{I_{v0}}^{I_{v\infty}} I_\theta(E) e^{-\mu(E)\hat{z}} dE$. Composite materials require that the respective contributions to the absorption of the individual chemical elements needs to be taken into consideration with the respective impact, expressed as $I = \int_{I_{v0}}^{I_{v\infty}} I_\theta(E) e^{-\sum_i \mu_i(E) \hat{z}_i} dE$.

Absorption cross sections for neutrons

[atomic, nuclear] σ , expressed as the PROBABILITY of a PARTICLE hitting a nuclear target with various light-reaction products as a result of the interaction, expressed as $(I/A) = n_a v_a$; $\sigma = \sum_j (N_j / n_a v_a n A \Delta \hat{z})$ (see Figure A.14).

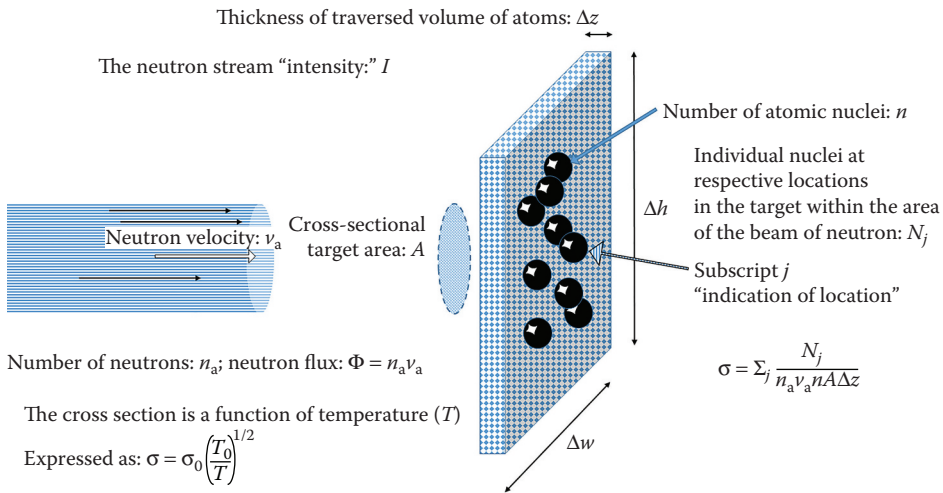


Figure A.14 Graphic representation of collision interaction, representative of absorption cross section.

Absorption cross sections for photons

[optics, solid-state] σ_a , radiant ENERGY is incident on a PARTICLE (molecule, ATOM) and is in its entirety converted into heat by definition of absorption (neglecting the release of lower energy photons as a contribution in absorption). The ratio of the total incident radiant power (P_a) on the volume containing the particle to the incident radiant energy on the particle within a specific SOLID ANGLE ($\Psi(\Omega')$), written as $\sigma_a(\Omega') = P_a / |\Psi(\Omega')|$. Generally the CROSS SECTION will be the average over a grouping within a volume (expressed in units $[m^2]$).

Absorption curve

[nuclear] Because of ENERGY interaction of specific mechanisms with a medium, the DECAY of the source energy or source material relies on the characteristic source energy or particulate size. For instance He^{2+} , monoenergetic electrons, beta rays, gamma rays, and visible light will have distinctly different decay patterns as a function of DISTANCE (see Figure A.15).

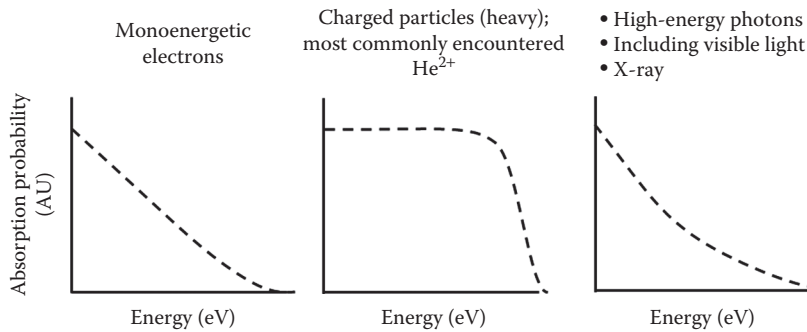


Figure A.15 Representations of the absorption curve energy spectrum for various interactions, based on particle and wave interaction.

Absorption edge

[nuclear] A ramp (not a discontinuity) in spectral performance of the ABSORPTION as a function of WAVELENGTH, primarily for semiconductor materials. Transition between the strong absorption of short wavelengths and the much weaker long-wavelength absorption, *also* “BAND-EDGE,” because there is a significant step in the absorption, respectively, the REFLECTION pattern is a function of wavelength. The onset wavelength of the ramp is a direct function of the transition between VALENCE and CONDUCTION ENERGY bands. The absorption edge is partially dependent on the PHOTOELECTRIC EFFECT (see Figure A.16).

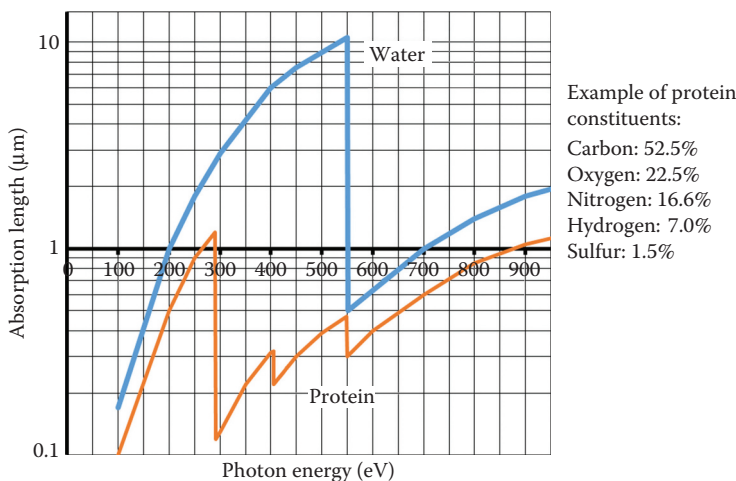


Figure A.16 Representation of the absorption edges at specific energy levels for photon interaction based on the available energy configuration of the molecules in the target specimen. The water absorption edge is representative of a specific vibrational resonance, whereas the protein is much more complex in its energy structure and associated translational, vibrational, and rotational resonance interactions.

Absorption edge for X-rays

[atomic, nuclear] Discontinuity in the ABSORPTION CURVE as a function of WAVELENGTH corresponding to a RESONANT absorption associated with a nuclear transition (as described energetically by the BOHR ATOMIC model and, for instance, the LYMAN SERIES) (see [Figure A.17](#)).

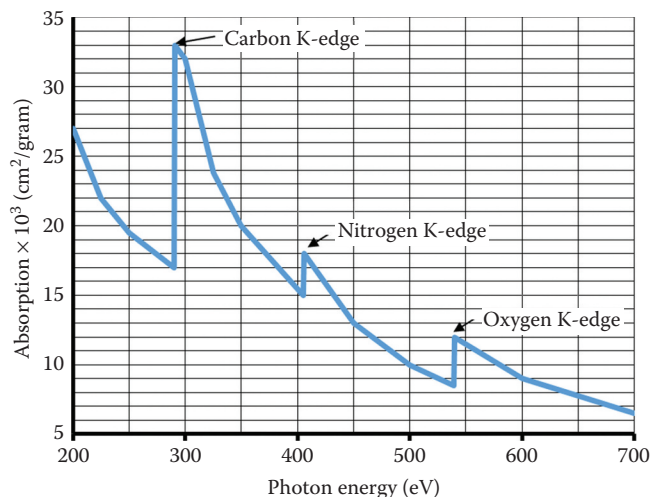


Figure A.17 Representative X-ray absorption spectrum for K radiation (electron orbit $n = 1$, the K-shell of the atom) for carbon, nitrogen, and oxygen atoms, respectively.

Absorption spectrum

[atomic, nuclear] Selective annihilation of specific WAVELENGTHS (i.e., SPECTRAL LINES) of ELECTROMAGNETIC RADIATION emitted from a BROADBAND source when passing through a medium (e.g., VAPOR, GAS, or transparent solid). The transmitted spectral profile displays a decreased MAGNITUDE compared to the incident profile of light at wavelengths that are conducive to absorption as a result of, for instance, the PHOTOELECTRIC EFFECT, conversion into HEAT, or PHOTON energy conversion to lower energy. The spectrum is typically a considered characteristic of the illuminated material (see [Figure A.18](#)).

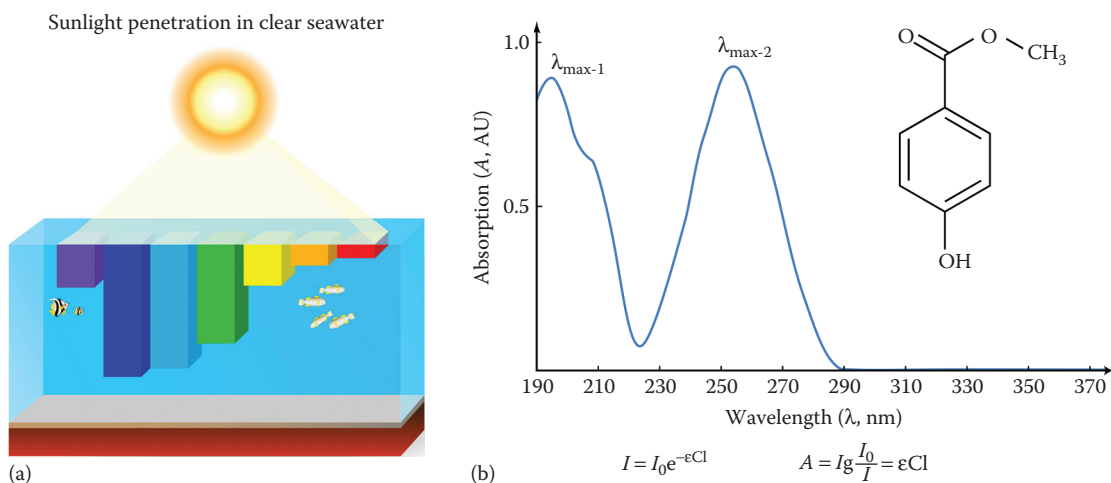


Figure A.18 Artist impression of absorption spectrum for water (a), the transmission of long wavelength ultraviolet for water yields a design requirement for fiber-optics operating with excimer laser (e.g., 308 nm) to have high OH contents (b), compared to low OH requirement for optical instruments operating in the red and infrared.

Abundance of stable isotones

[nuclear] The collection of ELEMENTS has a much larger number of stable isotones than unstable ones. This is primarily based on the high NEUTRON SEPARATION ENERGY for nuclei with a MAGIC NUMBER neutron quantity in the NUCLEUS.

AC

[electronics, general] Alternating current (abr.). In contrast to a fixed POLARITY ELECTRICAL POTENTIAL driving a constant CURRENT (i.e., DC). Generally pertaining to a single rhythm OSCILLATION in the AMPLITUDE of the ELECTRIC CURRENT as well as the associated driving VOLTAGE (i.e., AC voltage). The ELECTRONS will FLOW alternatively forward and backward in a CLOSED CIRCUIT. The principle applies both to a CURRENT SOURCE and a VOLTAGE SOURCE. The delivery of alternating current is usually provided in "SINGLE-PHASE" two-wire mechanism. The delivery of multiple single-phase currents that are OUT-OF-PHASE with each other (originally devised by NIKOLA TESLA [1856–1943]) overcomes the periodic lag of power delivery. The ideal configuration of maximum efficacy for power consumption is three wires that are 120° out of PHASE (i.e., 3-PHASE AC) (see [Figure A.19](#)).

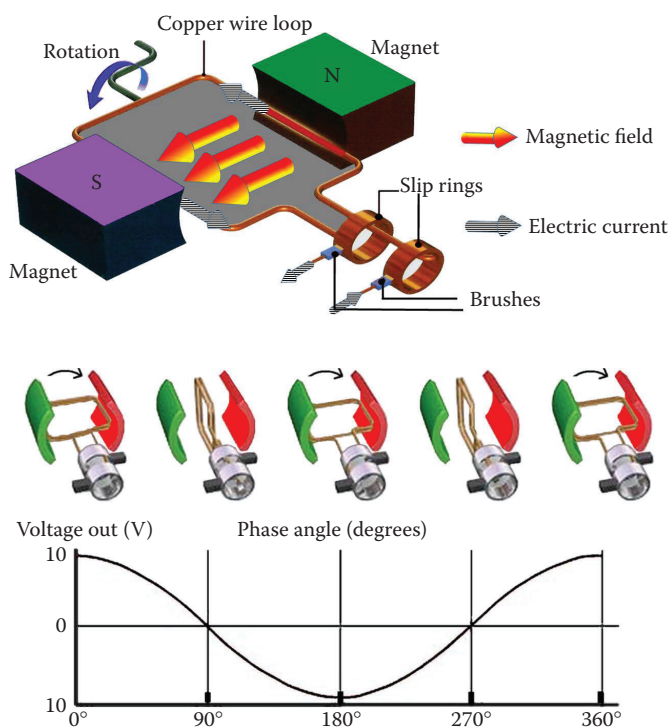


Figure A.19 Representation of the generation of alternating current resulting from a periodically increasing and decreasing captured magnetic field by an electric loop. Flux captured: dB/dt ; B =MAGNETIC FIELD passing through an area outlined by wire-loop, i.e. MAGNETIC FLUX.

AC capacitive circuit

[electronics, general] Electric circuit containing at least one CAPACITOR, which is charged and discharged under the following conditions: $q = CV_m \sin \omega t$, where q is the charge on the capacitor, C is the capacitance, V_m is the driving voltage, t is the elapsed time, and ω is the position in the oscillatory cycle or angular frequency. (Note: Current through the capacitor $I = dq/dt$.) The delay factor produced by the charging/discharging of the capacitor brings the voltage across the capacitor out of PHASE (delayed) from the driving alternating current/voltage by one quarter cycle (i.e., $\pi/2$ rad or 90°) (see [Figure A.20](#)).

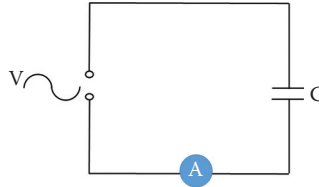


Figure A.20 Circuit diagram of a capacitor that is charged and discharged with the period of the alternating current applied by the sinusoidal fluctuating power supply.

AC circuits

[electronics, general] Electric circuits can contain any or all of the following components in PARALLEL and/or SERIES configurations: CAPACITOR (C), CURRENT SUPPLY, GENERATOR, INDUCTOR (L), RESISTOR (R), SUPERCONDUCTOR, VOLTAGE SUPPLY (BATTERY and device), and wire. Each component has its own typical frequency-dependent characteristics that influence the TIME-dependent ELECTRICAL CURRENT and VOLTAGE at any location in the circuit.

AC generator

[electronics, energy, general] Mechanism using a mechanical force to move an area (A), respectively, a MAGNETIC FIELD ($\vec{B}$) (which encompasses a magnetic FLUX: Φ_m through the normal projection of an area A) and induce a VOLTAGE (electromotive force voltage: ϵ_{emf}) that drives a CURRENT that alternates over TIME (t) with the direction of the magnetic field as described by the induced voltage or electromotive force $\epsilon_{\text{emf}} = \Delta\Phi_m / \Delta t = \Delta(\vec{B} \odot \vec{A}) / \Delta t = l * (\vec{v} \otimes \vec{B})$, whereas the magnetic field changes with velocity v and the field works on a circuit with length l , which can be the length of continuous loops in a coil. The current follows from OHM'S LAW: $I = V/R = \epsilon_{\text{emf}}/R$, where R is the compound electric RESISTANCE of the closed circuit (see [Figure A.21](#)).

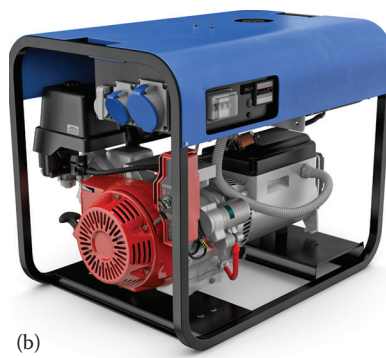


Figure A.21 Example of (a) an alternating generator, (b) a gasoline-powered generator, and (c) an electrical power generator.

AC induction motor

[electronics, general] See INDUCTION MOTOR.

A

Acceleration (a)

[general, geophysics, mechanics, nuclear] The incremental rate of change in velocity $\vec{v}$ of an object in direction (angular acceleration) or MAGNITUDE (linear acceleration) ($\vec{a} = d\vec{v}(t)/dt$), under the influence of the sum of all external forces ($\Sigma F = ma$). The direction of MOTION is taken as positive (m/s^2). For averaging the calculation of acceleration, average acceleration (a_{av}), greater time steps are used: $\vec{a} = \Delta\vec{v}/\Delta t$ (m/s^2) (see [Figure A.22](#)).



Figure A.22 Increase or decrease in linear acceleration. A change of direction and resulting decrease in velocity in the direction of prior flight pattern as well as new direction with increasing velocity in that direction as a result of acceleration for the Thunderbirds flight team.

Acceleration, angular (α)

[general, mechanics] The incremental rate of change of ORBITAL VELOCITY or ANGULAR SPEED (ω) expressed as $\alpha = d\omega/dt$ (rad/s^2).

Acceleration, centripetal (a_c)

[general, mechanics] (i.e., center-seeking) A rotating object is subjected to a continuous force that applies a change in direction irrespective of time. The rate of change in directional VELOCITY (vector velocity) provides the angular acceleration, which is directly linked to the CENTRIPETAL FORCE changing the direction. The

acceleration tied to the angular MOTION is defined by the ANGULAR VELOCITY (ω) as $a = v^2/r = \omega^2 r$, where v is the tangential component of the motion of an object in a circular path. This acceleration is directed toward the center of the circular motion (m/s^2) (see Figure A.23).



Figure A.23 Force balance in centrifuge (a,b) ensuring that the center of mass of the baskets is in equilibrium, causing the baskets to tip (c). The centripetal acceleration provides the force applied by the hangers to the baskets from flying off into a tangential path. Because of the centripetal force, the mass distribution in the test tube mounted in the basket is redistributed with heavy media toward the bottom of the test-tube (farthest outward point, due to tangential force) and lighter media closer to the axis of rotation. Similarly, in (d) the skateboarder is held normal to the curved surface due to the centripetal force, which in this situation exceeds the gravitational force resulting from the angular acceleration exceeding the threshold value for balance. In the rollercoaster (e), the centripetal acceleration exerted by the seats of the passengers will ensure a “comfortable” seat while rushing through the loop upside-down. Meanwhile, the back-rest will provide the (normal) force on the passengers to make them move forward. A force diagram provides the resultant force on the passenger.

Acceleration, due to gravity (g)

[general, geophysics, mechanics] See GRAVITATIONAL ACCELERATION. The acceleration of a freely falling body in a VACUUM; 9.80665 m/s^2 at 45° LATITUDE and at sea level.

Acceleration, in harmonic motion

[general, mechanics] SIMPLE HARMONIC OSCILLATION is described by the sinusoidal MOTION pattern of an object, operating at a single FREQUENCY. This means that the motion periodically changes direction as well as the VELOCITY. Using the fact that the unidirectional acceleration is the derivative of the motion velocity the acceleration is defined as $a = -A\omega^2 \cos \omega t$ (m/s^2).

Acceleration, radial (a_r)

[general, mechanics] See CENTRIPETAL ACCELERATION.

Acceleration, relationship to force and mass

[general] See NEWTON'S SECOND LAW.

Acceleration, tangential (a_t)

[general, mechanics] The rate of change in the tangential VELOCITY (v_t) between the final velocity (v_{tf}) and initial velocity (v_{ti}) measured spanning a time frame Δt , of a PARTICLE performing a circular MOTION defined as $a_t = (v_{tf} - v_{ti}) / \Delta t$, under the uniform motion $a_t = 0$ (m/s^2).

Acceleration in cyclotron

[atomic] A system made of two short-length, large-radius half-tubes (split along the longitudinal direction of the tube; apposing "D" shapes), which are placed under the influence of a MAGNET, creating a MAGNETIC FIELD along the length of the axis of the tubular geometry (see CYCLOTRON). ACCELERATION OF CHARGED PARTICLES (=ION) relies on NEWTON'S THIRD LAW, AMPÉRE'S LAW, and influenced by HANS CHRISTIAN OERSTED (1777–1851) to yield the MAGNETIC FORCE (F_m) on a PARTICLE with CHARGE q as $F_m = q * (\vec{v} \otimes \vec{B})$, with the magnetic field $\vec{B}$ and the injected particle velocity " $\vec{v}$," providing the acceleration $a = Z_e * (\vec{v} \otimes \vec{B}) / Au$, where Z_e is the VALENCE charge of the particle, A is the ATOMIC NUMBER of the ion, and u is the unified ATOMIC MASS, considering that effectively only one particle at a time is manipulated (see Figure A.24).



Figure A.24 Detail of particle accelerator, manipulating the path and velocity of ions by means of orchestrated magnetic field vectors in a confined environments.

Accelerator, particle

[atomic, nuclear] *See* PARTICLE ACCELERATOR.

Accelerator, Van de Graaff generator

[atomic] *See* VAN DER GRAAFF GENERATOR.

Acceptor impurity

[atomic] Atoms and molecules deviating from the norm or the GROUND STATE configuration such as charge carriers in SEMICONDUCTORS. For instance, in a crystalline configuration, an impurity ATOM may have one VALENCE electron that has the possibility of residing in CONTINUUM with the free electrons or getting bound to the atom in a preferential state.

Accommodation, of the human eye

[general] The ability to focus due to ADAPTIVE OPTICS in the LENS of the EYE. Muscular (i.e., CILIARY MUSCLE) ACTIVITY controls changes in the radius of curvature of the lens (CRYSTALLINE LENS) that determine the focal length based on the "LENS EQUATION," and is referred to as ACCOMMODATION. With the ciliary muscle totally relaxed, the eye is focused at infinity or defined as the "far point," which in practice means anything beyond 5 m DISTANCE. The total contracted ciliary muscle focuses the eye in the "NEAR-POINT," which allows correct and undeformed sharp focused VISION of an object placed at approximately 25 cm distance for the average human being. Aberrations in the vision achieved by the accommodation of the crystalline lens are primarily defined by two conditions: presbyopic (far-sighted), which is also classified as hypermetropia, and MYOPIA (near-sighted), respectively (see [Figure A.25](#)).

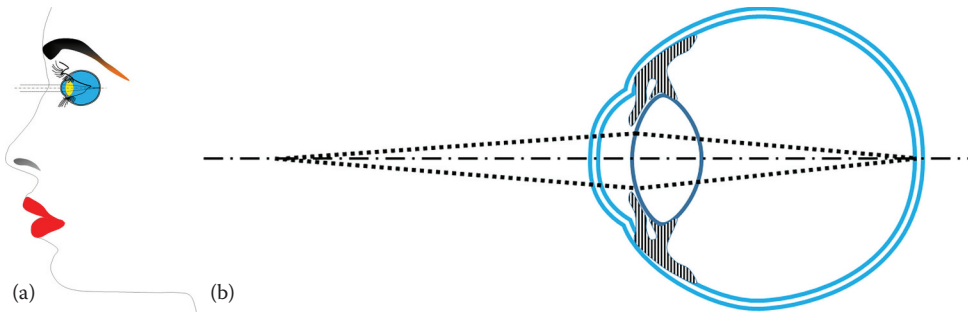


Figure A.25 (a) The manipulation of the focal length of the eye by means of the ciliary muscle (i.e., accommodation) and (b) relaxing for focusing an object at close proximity on the same retinal distance as a far-away object, allowing the lens to bulge-out. The focal length is a function of the radius of curvature of the curved surfaces enclosing the gel lens calculated with the "lens equation."

Achromatic lens

[optics] A composite LENS with two or more layers, each respective material of uniform index of REFRACTION that compensate each other (eliminating DISPERSION) for the inherent refractive CHROMATIC ABERRATION of the individual material properties.

Achromatic prism

[optics] A composite PRISM with two or more prisms, each of uniform index of REFRACTION that compensate each other (eliminating DISPERSION) for the inherent refractive CHROMATIC ABERRATION of the individual material properties, allowing the emitted light to maintain the incident COLOR temperature, only offset in optical path.

Acid

[biomedical, chemical] LIQUID with pH less than 7 ($\text{pH} < 7$), that is, a high concentration of hydrogen ions. Acids are corrosive media used to dissolve solids, such as metals and cement; for instance, hydrochloric acid is used to remove excess cement in construction (see [Figure A.26](#)).

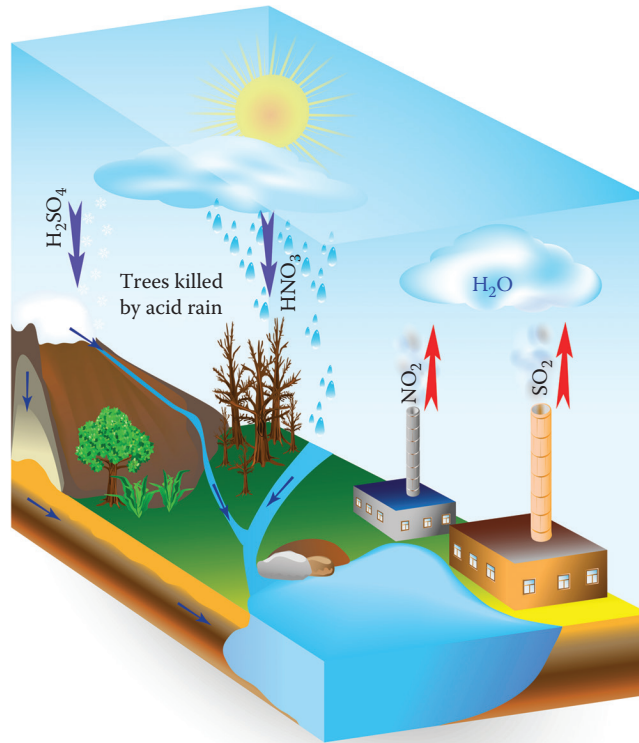


Figure A.26 Diagram of the formation and impact of acid rain. High acidity is corrosive and disintegrates biological life forms as well as inorganic media. One example of acid rain impact on the urban environment is the diminished structural integrity of concrete, visible in buildings and statues.

Acoustic impedance (Z)

[biomedical, computational, mechanics] It is a measure of how reactive the medium is to pressure wave disturbance. Acoustic impedance implies that the medium has both elastic and viscous properties. The acoustic impedance relates to ULTRASONIC IMAGING. The mismatch of acoustic impedance at an interface between two media will result in a wave propagation that obeys SNELL'S LAW in both REFRACTION and REFLECTION. The acoustic impedance is the ratio of the pressure wave MAGNITUDE (P) to velocity of a PARTICLE (v) in the medium and is written as $Z = P/v = \rho v$, where ρ is the local transporting medium density. For low frequencies, the acoustic impedance reverts to acoustic resistance, sometimes also referred to as ACOUSTIC REACTANCE.

Acoustic impedance tomography

[acoustics] Imaging modality that uses acoustic transmission and REFLECTION signals to form a density IMAGE of an inhomogeneous medium. This method of imaging is used in industrial quality control (nondestructive) and defect detection, medical diagnostics, and guidance (SONOGRAPHY or sonar). A special case is ULTRASONIC IMAGING (*see* ULTRASOUND IMAGING) (*see* [Figure A.27](#)).

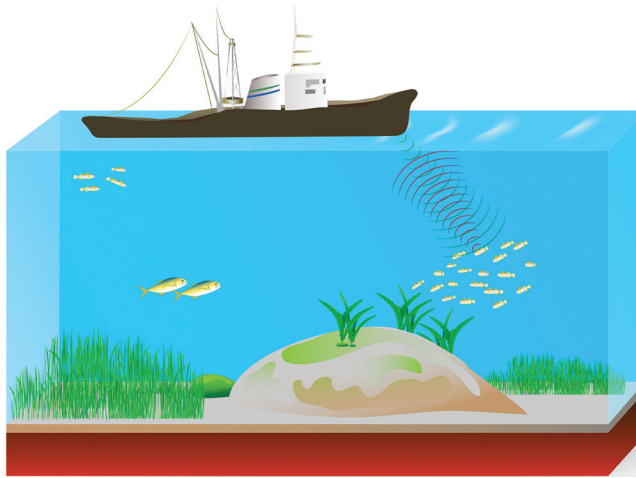


Figure A.27 Artist impression of acoustic impedance imaging, locating the size of fish and the size of the school of fish. Alternatively, sonographically outlining the contour and composition of the sea floor.

Acoustic intensity (I_{acoustic})

[acoustics] The acoustic intensity, also called “sound level,” is directly proportional to both the square of the AMPLITUDE of the compression wave ($\mathcal{A}$) and the square of the FREQUENCY (ν) as $I_{\text{acoustic}} \propto \nu^2 \mathcal{A}^2 = \nu^2 P_{\text{acoustic}}^2$, because $P_{\text{acoustic}} \propto \mathcal{A}$ (*see* [Figure A.28](#)).



Figure A.28 Acoustic lithotripsy used for the breakdown of kidney stones or gall stones by means of focused high-energy mechanical vibration.

Acoustic intensity method (AIM)

[fluid dynamics] Mechanism of action to “visualize” the acoustic energy flow and determine the acoustic power. The visualization process takes places through NUMERICAL reconstruction. Experimental applications may use, for instance, OIL-FILM METHODS. More advanced experimental methods include hot-wire ANEMOMETER, PITOT TUBE, LASER SPECKLE velocimetry, SCHLIEREN IMAGING, and injection-tracer methods (e.g., smoke and dye). One specific application may use the STEREOSCOPIC SOUND intensity MEASUREMENT and calculated reconstruction of the SONIC PRESSURE vectors distribution (e.g., finite ELEMENT computation) in the respective plane defined by the placement of MICROPHONES. One specific application is in background noise-reduction architectural design validation.

Acoustic power (P_{acoustic})

[general] The concepts of power and intensity in ACOUSTICS are directly related to the rate of MECHANICAL ENERGY transfer and the rate of energy transfer across a unit surface area. The average acoustic power (P_{acoustic}) and intensity (I_{acoustic}) are linked by the following equation: $I_{\text{acoustic}} = P_{\text{acoustic}} / A$.

Acoustic reactance

[biomedical, computational, mechanics] See ACOUSTIC IMPEDANCE.

Acoustic resistance (R_a)

[biomedical, computational, mechanics] It is a measure of how resistant the medium is to pressure wave disturbance. Acoustic resistance implies attenuation only, elastic and viscous properties. RESISTANCE is expressed as $R_a = (\rho G_\infty)^{1/2}$, where ρ is the density of the medium and G_∞ the stiffness or SHEAR MODULUS.

Acoustic waves

[general] Also SOUND WAVES are periodic COMPRESSION and EXPANSION patterns propagating through a MEDIUM. Acoustic waves are LONGITUDINAL waves, in contrast to ELECTROMAGNETIC waves (i.e., TRANSVERSE). The AMPLITUDE of acoustic waves is derived from the MOLECULAR MOTION or the local PRESSURE. Acoustic waves require a medium, unlike electromagnetic waves (see [Figure A.29](#)).



Figure A.29 Illustration of a mechanical surface wave resulting from the impact of a drop on the interface between air and water.

Acoustic waves, intensity-level (β)

[acoustics, general, mechanics] Sound intensity is frequently expressed as a relative MAGNITUDE, referenced against the intensity (i.e., pressure) threshold for audibility at 1000 Hz. The HEARING threshold is standardized as $I_{\text{acoustic}_0} = 1.0 \times 10^{-12} \text{ W/m}^2$. The concept is derived from the nonlinear (actually logarithmic, such as many human sensory sensations) response of the human EAR; a sound level that is ten times larger is perceived as only twice as loud. The intensity level is expressed in DECIBEL (dB), which is derived as $\beta = 10 \log_{10}(I/I_0)$.

Acoustical engineering

[biomedical, fluid dynamics, general] The science and ENGINEERING aspect of generating, propagating, transmitting and receiving, and processing of longitudinal pressure waves, primarily identified as SOUND; theoretical and practical implications of moving solid bodies, liquids, and gaseous mixtures. Because of the mechanism of action, the field of ACOUSTICS includes elastic theory in mechanical engineering and FLUID- and AERODYNAMICS. In principle, the field of acoustics was established in the last part of the seventeenth century with the publication of works by the French physicist and mathematician JOSEPH SAUVEUR (1653–1716), who incidentally was deaf himself (see [Figure A.30](#)).



(a)



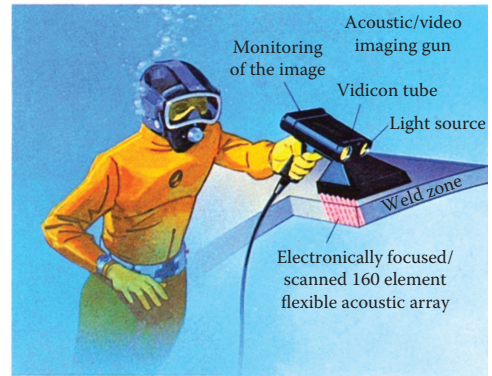
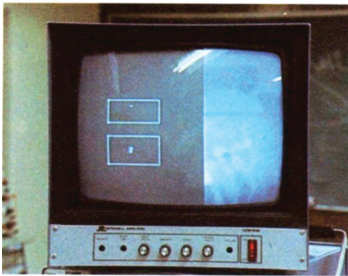
(b)

Figure A.30 (a) Example of mechanical design to provide a unique sound generated by the metal straight flute played by Ian Anderson of the rock group Jethro Tull and (b) drawing of the pioneer in acoustical analysis: Joseph Sauveur (1653–1716), a physicist from France.

Acoustical holography

[acoustics] Using both AMPLITUDE (pressure) and PHASE of the mechanical waves collected by specific sensors (see ACOUSTIC INTENSITY METHOD), an IMAGE can be formed from dispersed and reflected SOUND waves similar to optical holography. Generally, ACOUSTICAL HOLOGRAPHY is a near-field technique with RESOLUTION and accuracy directly dependent on the number of sensors. A reconstruction algorithm uses finite ELEMENT methods and computational PHYSICS as required for the complexity of the diagnostic design. The three-dimensional representation of the ENERGY distribution yields the geometric and material information of the polymorphic construction under investigation. Time-domain analysis can additionally provide

MOTION artifacts such as FRICTION (and other density and contact surface interaction related characteristics) (see Figure A.31).



Acoustical Holography is a technique which allows three-dimensional images of steel through its thickness to be displayed.

A diver held probe is placed near the weld under inspection and, using reflected ultrasonic waves, produces images on a television monitor at different planes through the thickness of the material.

All the monitoring equipment is within the submersible under the supervision of skilled operators. After the dive, the television and raw data records can be further interpreted and hard copies made if necessary.

Figure A.31 Artist impression of nondestructive testing using acoustic imaging. Based on the interference pattern between the incident and backscattered pressure wave an image can be reconstructed resulting from amplitude as a function of time of flight. The interference principle provides accuracy within a half-wavelength depth of field. The lateral resolution is primarily a function of the focusing ability of the device.

Acoustics

[acoustics, biomedical, fluid dynamics, general, mechanics] The experience of SOUND and mechanical WAVES (primarily in the short WAVELENGTH range below 40,000 Hz), these waves are COMPRESSION WAVES or TRANSFERS WAVES. In architecture and structural ENGINEERING, this relates to the propagation and remission REVERBERATION of sound in a semi- or fully enclosed environment. The word "ACOUSTICS" is derived from the Greek word $\alpha\kappa\omicron\upsilon\sigma\tau\iota\kappa\omicron\varsigma$, meaning "able to be heard." Acoustics is also the science of (1) creating sound and either (2) maintaining the FREQUENCY SPECTRUM most accurately or using the information incorporated in the transmission through a medium or architecture, and subsequent (3) detection and analysis in order to derive information from the obstacles in the path, BATS providing the most obvious example. Propagation of density waves in solids or liquids is called an ELASTIC WAVE. The propagation of a homogeneous plane density WAVE traveling in the z -direction can be described as the changes in a slab of undisturbed compressible medium with the cross-sectional area $\hat{A}$ and thickness $d\hat{z}$, contained between planes at location $\hat{z}$ and $\hat{z} + d\hat{z}$ and mass $\rho_0 \hat{A} d\hat{z}$, where ρ_0 is the density of the undisturbed medium at location $\hat{z}$, with pressure P_0 . Upon compression/EXPANSION resulting from the acoustic wave, the plane at $\hat{z}$ will be displaced by ζ , whereas the plane at location $\hat{z} + d\hat{z}$ will be displaced by $\zeta + (d\zeta/d\hat{z})d\hat{z}$ with $(d\zeta/d\hat{z}) \ll 1$, with a local pressure gradient resulting in accelerated MOTION of the FLUID plane over the DISTANCE ζ . This situation may best describe a PIPE organ or a flute. Under this condition, the process can be assumed to be ISOTHERMAL, which will not be the case for a large change in motion or significant pressure changes. The net force acting on the surface at location $\hat{z}$ that is directly proportional to the local transient excess pressure ($P_{AC} = P_t - P_0$), with P_t the instantaneous pressure at any point in the wave, expressed as: $dF_{\hat{z}} = \{P_{AC} - [P_{AC} + (dP_{AC}/d\hat{z})d\hat{z}]\} \hat{A} = -(dP_{AC}/d\hat{z})d\hat{z} \hat{A}$ as derived from NEWTON'S EQUATION OF MOTION. Under NEWTON'S SECOND LAW, the force per unit volume is now defined as $-(dP_{AC}/d\hat{z}) = \rho_0 (d^2\zeta/dt^2)$. Because the medium is considered compressible, the cross-sectional area will be

considered constant for now, yielding for the CONSERVATION OF MASS of the elastically deformed medium: $\rho_0 \hat{A} d\zeta [1 + (d\zeta/dz)] = \rho_0 \hat{A} dz$, and the condensation/EVAPORATION at point z can be defined as $\Xi = (\rho - \rho_0)/\rho_0$. Assuming only small amplitude, with respective small condensation and displacement, yields the EQUATION OF CONTINUITY as $\Xi = -(\partial\zeta/\partial z)$. Under continuously varying pressure (i.e., sound wave), the condensation will continuously change sign, condensation/evaporation (compression/expansion, respectively). Because the movement in the medium is so small and of relatively short duration, the process can be considered adiabatic. Using the BOYLE–GAY–LUSSAC LAW applied to an isothermal and ADIABATIC process gives $P_{AC}/P_0 = (\rho/\rho_0)^\gamma$, where γ is the adiabatic constant ($\gamma = 1.4$ for AIR). After substitution of Newton's second law of motion can be written as $(d^2\zeta/dt^2) = \Phi'^2 \left[(d^2\zeta/dz^2) - (\gamma + 1)(d\zeta/dz)(d^2\zeta/dz^2) \right]$, where $\Phi' = \gamma P_0/\rho_0$ is the velocity of propagation of the acoustic wave front in the z -direction. In order to solve for displacement, a zero order approximation only considers the first term: $d^2\zeta/dt^2 = \Phi'^2 (d^2\zeta/dz^2)$, with SOLUTION $\zeta = f[t - (z/\Phi')]$. Under a driving compression with simple HARMONIC OSCILLATION $f(t) = C_1 \cos(\omega t)$, where C_1 is the AMPLITUDE, or stroke of the compression (e.g., sound-board and piston), and ω is the ANGULAR VELOCITY with associated frequency $\nu = \omega/2\pi$, the displacement will be described by $\zeta(t) = C_1 \cos \omega[t - (z/\Phi')] + \left[C_1^2 (\gamma + 1) \omega^2 / 8 \Phi'^2 \right] \zeta \{1 - \cos \omega[t - (z/\Phi')]\}$. The solution now no longer describes a SIMPLE HARMONIC MOTION of the particles in the plane of the medium; the second term captures the distortion imposed by the condensation/vaporization process. On a larger scale, this process can be used to describe the destructive impact (e.g., ultrasonic cleaner) or to facilitate drug-delivery in biomedical application. The processes of condensation and vaporization in these two examples involve farther deviation from harmonic oscillation to include BUBBLE expansion and CAVITATION. The science of architectural acoustics can be attributed to WALLACE CLEMENT SABINE (1868–1919), a Harvard professor of PHYSICS. The design of a concert hall is one example involving acoustics; other applications are in SPEAKER boxes and the musical instruments themselves. The TRANSVERSE PRESSURE WAVE generated by a specific source will be encountering obstacles that will reflect and change the spectral profile before the sound is detected. One detection device is the EAR (see Figure A.32).



(a)



(b)

Figure A.32 (a) Pioneer of acoustical design Wallace Sabine (1868–1919) from the United States. (b) Modern acoustically accurate concert hall design.

Rhythmic mechanical COMPRESSION and EXPANSION WAVE at FREQUENCIES ranging from 10 to 30,000 Hz. This phenomenon also generates SOUND when exposed to the human EAR. Frequencies in excess of 30,000 Hz are generally categorized as ULTRASOUND. In addition to human speech, communication, and music, acoustics is also used for sensing and diagnostics. In quality control, acoustics is used for nondestructive testing, whereas in biological applications, ultrasound can IMAGE inside live tissue up to great

depths without the risk for side-effects from exposure to the ENERGY source. In comparison, other medical imaging techniques such as X-RAY, MRI/fMRI and PET have health concerns associated with the respective probing energy sources. In other modalities, animals use acoustics for the equivalence of VISION, where frequencies up to 300,000 Hz are used, for instance, by BATS for guidance. Acoustics is also used for guidance by dolphins, submarines, and to assist the blind through obstacles and surface irregularities. The human ear is generally sensitive in the frequency range of 20 Hz–20 kHz, with peak sensitivity around 1000 Hz (see HEARING) (see Figure A.33).

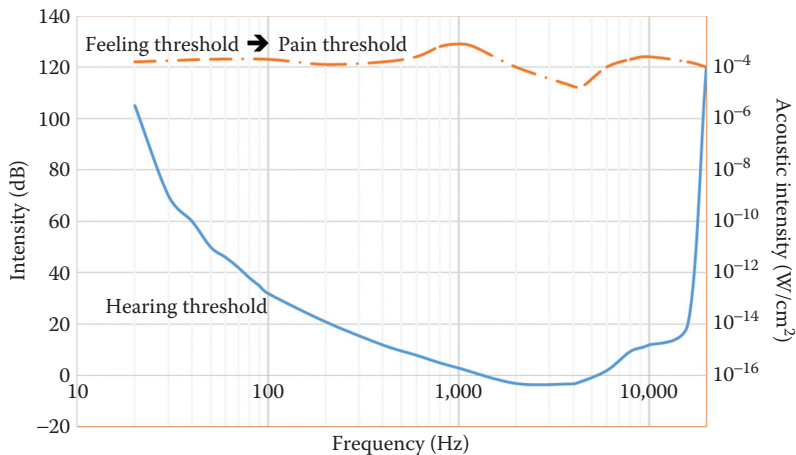


Figure A.33 The human acoustic perception threshold spectrum as well as pain level in the ear when exposed to sound of various magnitudes.

Acoustics, superposition of wave

[general] See WAVE SUPERPOSITION.

Acoustoelectric effect

[acoustics] Generation of ELECTRICITY in a semiconductor material (PIEZOELECTRIC SEMICONDUCTORS) and certain metals when an acoustic wave passes through a medium block. The medium will need to have access to mobile charges for the phenomenon to become apparent. The mechanical strain created by the acoustic deformation locally generates electric field gradients, which travel with the WAVE, generating a mechanism to induce the FLOW of charges. In nonpiezoelectric media, the mechanism of action is the induction of a shift in CARRIER ENERGY of the molecular composition in response to the strain. The resulting formation of electric current is actually correlated to the SOUND intensity but not to frequency. The apparent correlation between moving charges and acoustic energy alludes to the fact that an external electric field may be used to amplify the mechanical deformation. This phenomenon is supported in several piezoelectric materials, general under an applied field in excess of 700 V/cm, at specific material-dependent RESONANCE frequencies (relevant parameters are constituents and dimensions). The theoretical explanation of the acoustoelectric gain/acoustoelectric amplifier mechanism is the fact that a condition must be reached where the charge carrier DRIFT VELOCITY must match the SHEAR WAVE VELOCITY (see Figure A.34).

depolarization influences. *Also see* ELECTROMYOGRAM (EMG; muscular activity IMAGE) *and* VOLUME CONDUCTION (see [Figure A.35](#)).



Figure A.35 The collection of the changes in electrical muscle activity because of the changes in density associated with muscle contraction, next to the physical volume conduction aspects of the acute depolarization itself. Once the muscle is starting to contract the depolarization wavefront is altered because of the changes in electrical conductivity due to density changes (i.e., the “acoustic effect”). In this manner, the muscle contraction with respect to frowning or smiling can be quantified. Note that one uses more muscles to smile than to frown.

Actin

[biomedical] Protein that is an active part of the CONTRACTION mechanism of STRIATED MUSCLE. ACTIN in filament shape is a globular POLYPEPTIDE chain made out of helical POLYMER consisting primarily of amino acids. Actin interacts with MYOSIN for contraction (see [Figure A.36](#)).

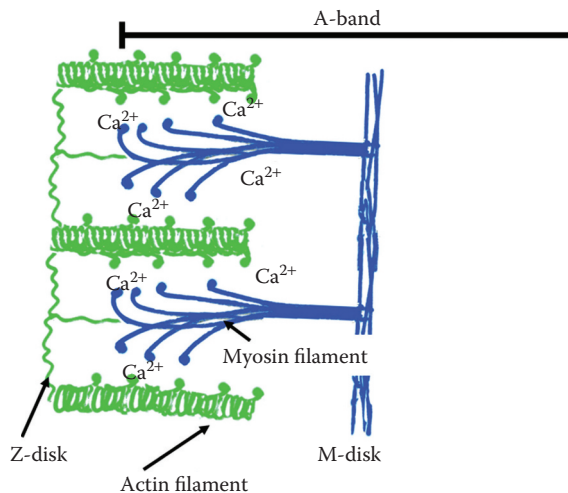


Figure A.36 Graphical representation of the microscopic filament in the muscle paired with myosin that provides a means for contraction by incremental shortening of the muscle file, allowing the actin to be attracted by sequential myosin molecular chains, gradually moving the actin toward the M-band, one molecular “feather” at a time.

Actinium

[nuclear] Symbol (Ac), radioactive ELEMENT in “METAL”-group IIIb, atomic number $Z = 89$ with a half-life of 21.6 years, electron configuration: $[\text{Rn}]7s^26d^1$, meaning the inner core has the electron configuration as radon (Rn). Commonly found in uranium ores and is a segment of the uranium DECAY chain, which has inspired the decay: $A = 4n + 3$ chain of uranium-235 to be named the ACTINIUM series.

Actinium, radioactive series

[atomic, nuclear] DECAY chain within the uranium decay commonly used to determine geologic age using the ACTINIUM-D/radium-G ratio to ascertain age beyond a billion years.

Action at a distance

[general, nuclear] Objects exerting forces without apparent physical contact across an intervening void. A few examples include GRAVITATIONAL FORCE, VAN DER WAALS FORCE, STRONG NUCLEAR FORCE, and WEAK NUCLEAR FORCE.

Action potential

[biophysics, chemical, electromagnetism, energy] Specific cells have the ability to exchange ions that will generate an electrical potential across the cellular MEMBRANE, the NERNST POTENTIAL. When the TRANSMEMBRANE NERNST POTENTIAL exceeds a set threshold (cell-specific) the membrane opens the ION gates and the ELECTRIC POTENTIAL (V) changes. This process becomes self-sustaining and supports the migration along the length of the CELL MEMBRANE. Specific cells capable of generating an ACTION POTENTIAL are nerve cells and cardiac MUSCLE cells. This electrical potential is part of both an active and passive transmembrane ion transportation system and is short-lived (order of milliseconds). The CELL membrane can be part of either the axon or dendrite from a nerve cell, or a cardiac muscle cell grouping. The minimally required ion current to initiate membrane DEPOLARIZATION is referred to as RHEOBASE. The stimulus to reach an action potential can be of high intensity, short duration or low intensity and long duration. The excitation mechanism of action is cell specific, such as PRESSURE (e.g., touch), TEMPERATURE, or MOTION (e.g., HEARING), chemical (e.g., taste), or LIGHT (e.g., EYE). The cell communicates with neighboring cells as well as with the autonomic and PARASYMPATHETIC NERVE SYSTEM to regulate their own chemical ACTIVITY as well as balance with the organ or tissue they are an integral part of. Nerve cells communicate observations and commands respectively to and from the brain as well as autonomic and parasympathetic nerve system to achieve a predefined goal. Some of the specific functions of action-potential transmission are heartbeat, VISION, hearing, flight from harm, or danger, and for general sensing purposes such as carboic acidity related to carbon dioxide SATURATION of the BLOOD (RESPIRATION), the acidity of the blood and lymph, core temperature, and proprioception, to name a few. Before describing how electrical impulses travel through a MOTOR unit, the concept of MEMBRANE POTENTIAL (V_m) needs to be reviewed (*see* MEMBRANE POTENTIAL). In addition to the capacitive charge under equilibrium, the electronic model for an action potential involves the FLOW of ionic current (displacement current) that needs to be characterized by resistive ELEMENTS. The ion pumps (e.g., Na^+/K^+ -pump) are voltage sources in this electronic modeling. The capacitive discharge of one segment of the cell (i.e., nerve) is the initiation of an action potential, causing the neighboring elements to follow suit by chemical and electronic COHESION of the membrane. The DEPOLARIZATION will travel over the membrane along the length of the cell as if it were a series circuit, and hence the electric discharge wave-propagation will obey the TELEGRAPH EQUATION. SIR ALAN LLOYD HODGKIN (1914–1998) and SIR ANDREW FIELDING HUXLEY (1917–2012) built on these previously devised equations and developed an equation that factors in not only relative ion concentrations and permeability but also mean conductance through individual channels and inherent membrane properties such as capacitance and OPEN-CHANNEL and closed-channel probabilities. $i_m = i_{ml} + C_m (\partial V_m / \partial t) = (1/R_i + R_c) (\partial^2 V_m / \partial \tilde{x}^2)$, or when considering the propagating action potential described by the respective ion migrations: $i_m = (V_m - V_{\text{Na}})g_{\text{Na}} + (V_m - V_{\text{K}})g_{\text{K}} + (V_m - V_{\text{ion-leak}})g_{\text{ion-leak}} + C_m (\partial V_m / \partial t)$, where $\tilde{x}$ is the DISTANCE along the length of the depolarizing cell (e.g., nerve axon [nonmyelinated/unmyelinated] or muscle), i_m

the membrane current per unit length, i_{mi} the ionic constituent of the transmembrane current per unit length, C_m the MEMBRANE CAPACITANCE per unit length, t time, R_i and R_e the intracellular and extracellular RESISTANCE, respectively. With g_s , the ionic conductance for ion S , this coefficient become the ruling parameter in the depolarization process. The ionic conductance is defined with a time dependence that relates to a variety of factors, including the transfer rate for a fixed number of particles (n_i) from closed to open state of the pores in the membrane expressed by the transfer rate coefficient: α_{n_i} , similarly from open to closed: β_{n_i} , with n_i the fraction of particles engaged in the “open” state and the compliment $1 - n_i$. The PROBABILITY of open/closed state is linked as: $dn_i/dt = \alpha_{n_i}(1 - n_i) - \beta_{n_i}n_i$, also known as the “transition probability.” The conductance for each of the ions is time dependent when the transition probability is included, specifically for POTASSIUM (K): $g_K = \bar{g}_K n_K^4$ (4 open units) and for SODIUM (Na): $g_{Na} = \bar{g}_{Na} m_{Na}^3 h$, where m_{Na} is the sodium equivalent open units (3 open) and h the closed number of units (1 this case). There is a time constant associated with the migration process, which is defined as $\tau_n = 1/(\alpha_n + \beta_n)$, with this parameter the probability of “open” unit is defined by the following equality: $\tau_{nK}(V_m) dn_K/dt = n_{K\infty}(V) - n_K$, same for “ m_{na} ” and the steady-state “probability” is delineated as $n_\infty = \alpha_n/(\alpha_n + \beta_n)$, which allows the “port open” to be defined as: $n_{n'} = n_\infty - (n_\infty - n_0)^{-t/\tau_n}$, with t representing time and n_0 the initial “open” probability. The propagation of the membrane voltage depolarization is governed by the “telegraph equation,” including a WAVE characteristic as well as a “DIFFUSION” (i.e., transmembrane ionic diffusion, both active and passive) part: $(d^2V_m/dt^2) - (c_1 + c_2)(dV_m/dt) = c_3^2(d^2V_m/dz^2) + c_1c_2V_m$, where $c_3^2 = 1/L_p C_m$, $c_1 = (1/C_m)(1/R_m d\tilde{z})$, and $c_2 = R_p/L_p$ with $\tilde{z}$ being the direction of propagation along the length of the cell (axon), and subscripts p and m with respect to the direction of propagation and membrane, respectively. Generally, the inductance (L), capacitance (C), and resistance (R) are all defined per unit length of the membrane. The action potential migration reduces to $d^2V_m/dt^2 = c_3^2(d^2V_m/dz^2)$ in the absence of RESISTANCE and transmembrane ionic current, which is a plain HARMONIC OSCILLATION, which will never apply. In case of a myelinated axon, the action potential “jumps” from the “NODE OF RANVIER” to subsequent “node of Ranvier,” which has a distinctly different propagation pattern than for the unmyelinated axon or muscle as described first. At each node of Ranvier, the initiation process is the arrival of an electrical current, which changes the local transmembrane potential due to the localized intercellular POLARIZATION of the membrane, raising the transmembrane potential above the threshold for the ion gates to open and the cell membrane is depolarized only at the node of Ranvier in a circumferential manner. The localized depolarization creates a potential difference with the next node of Ranvier, while the prior “node” is still in restoration model (ionic efflux/influx) to reestablish rebase. The potential gradient in this case will induce an ordinary current along the intercellular surface of the membrane. The current is much faster than the migration of the membrane depolarization train, virtually instantaneous (i.e., “speed of light”), which makes the MYELINATED NERVE a much faster CONDUCTOR.

Depolarization patterns

The MEMBRANE current balance in this case is written as $2\pi r_1 \Delta \tilde{z} \epsilon_m (\partial \epsilon_m / \partial t) + 2\pi r_1 \Delta \tilde{z} (i_m - i_e) = (\pi r_1^2 / r_L)(\partial \epsilon_m / \partial \tilde{z})_{\text{left}} + (\pi r_1^2 / r_L)(\partial \epsilon_m / \partial \tilde{z})_{\text{right}} = (\partial / \partial \tilde{z})[(\pi r_1^2 / r_L)(\partial \epsilon_m / \partial \tilde{z})] \Delta \tilde{z}$, where i_e is the current density over the surface of the cylinder of the axon (with radius $[r_1]$), ϵ_m is the electromotive force transmembrane potential generated by the ION migration such as the Na/K-pump, the variable $\tilde{z}$ can now no longer be treated as continuous. The ability to support a current the entire length of the axon would require an excessive amount of ENERGY and would be difficult to control. The electrochemical communication between clusters of nerve cells at the synaptic connections between sequential cells will create a mechanism of amplification as well as redundancy. The myelinated impulse transmission can be described as a discrete or step-wise. The internal resistance (R_i) through compartments enveloped by the Schwann CELL are defined by the intrinsic RESISTANCE of the cell and its ionic migration (r_i), where the cross-sectional area is defined by the radius of the axon (r_1) as follows: $R_i = r_i \ell / \pi r_1^2$ where ℓ is the DISTANCE between the nodes of Ranvier. The capacitance across the membrane of, for instance, an axon (C_m) is the localized capacity of the ion exchange (c_m) multiplied by the surface area (A) of the axon shell enclosed by the myelin sheath ($A = 2\pi r_1 \ell$) as $C_m = 2\pi r_1 \ell c_m (2r_1/r_2 - r_1)$. The length over which there is no ACTION POTENTIAL, because there is no transmembrane ion exchange (the distance between the nodes of Ranvier), is defined as the ELECTROTONIC LENGTH (λ_ℓ): $\lambda_\ell = \sqrt{(\pi r_1^2 R_m / 2\pi r_1 R_\ell)} = \sqrt{(r_1 R_m / 2R_\ell)}$. The DEPOLARIZATION process, by default, has a resistor–capacitor (RC)

time constant: $\tau_\ell = r_m c_m$ because that the membrane is a CAPACITOR with a resistive transmembrane ion flow. For a large electrotonic length (i.e., the Schwann cell covered section of the myelinated axon), the depolarization potential needs to be larger than for a short electrotonic length (unmyelinated axon; here, the electrotonic length is from the next ion port over). The depolarization process in a myelinated axon becomes especially important when considering multiple sclerosis, which destroys the myelin. In order to demonstrate the complexity of the segmented depolarization, the modified WAVE EQUATION for the myelinated axon is given without providing the full SOLUTION. The full SOLUTION requires advance mathematics: $\lambda_\ell^2 [\partial^2 \varepsilon_m(\xi, t) / \partial \xi^2] - \varepsilon_m(\xi, t) - \tau_m [\partial \varepsilon_m(\xi, t) / \partial t] = I_{\text{diff}}(\xi, t) = -\lambda_{\ell n}^2 [\partial^2 V_s(\xi, t) / \partial \xi^2]$, where V_s defines the potential difference between two neighboring nodes of Ranvier, and I_{diff} the ion DIFFUSION displacement current (see Figure A.37).

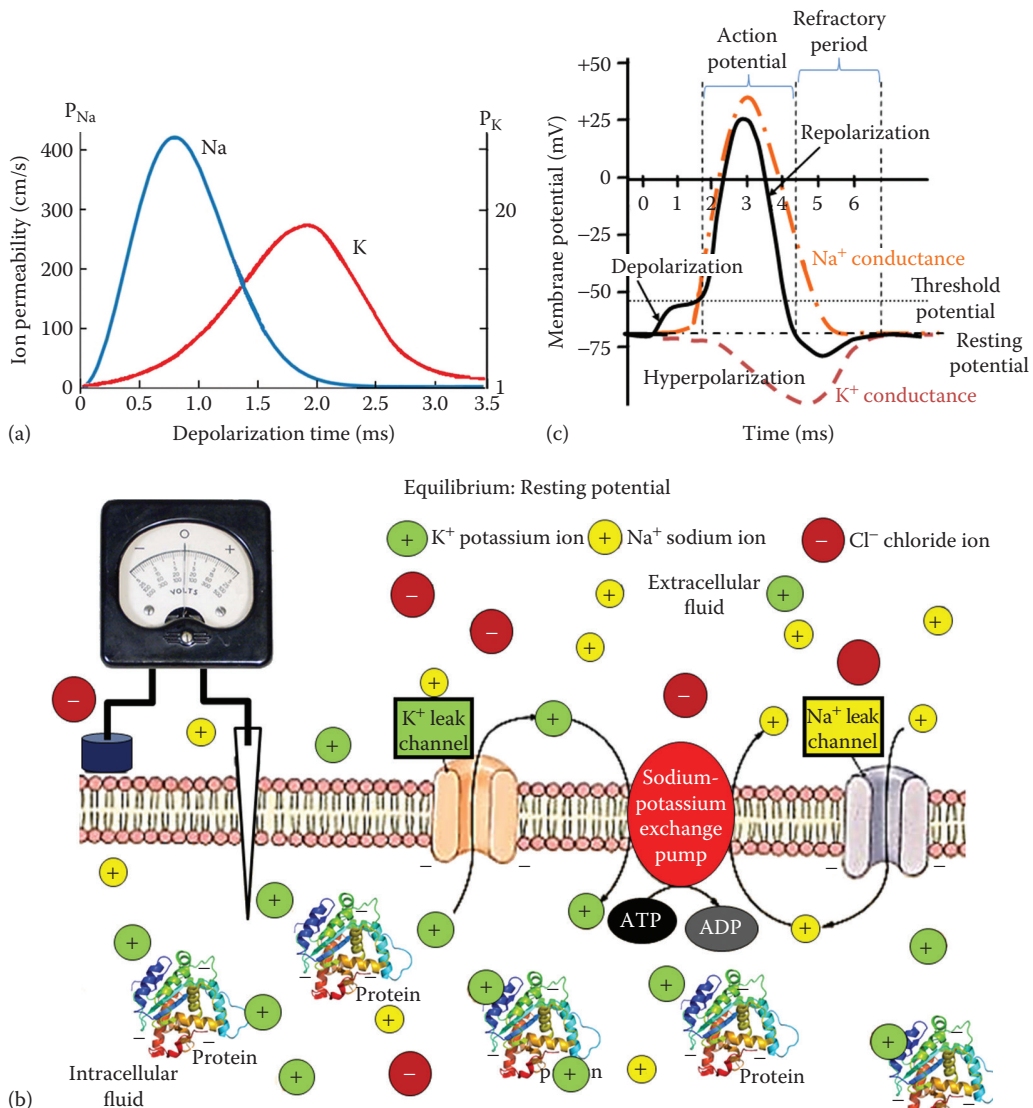


Figure A.37 Ionic mechanism involved in the generation of an action potential for a biological organism: (a) the transmembrane ionic diffusion rate of two of the primary ions: potassium (K⁺) and sodium (Na⁺) from inter- and extracellular locations involved in the formation of the action potential, (b) the mechanism of action with respect to the transport of sodium and potassium by means of active pump mechanism as well as gates that open or close, providing the opportunity for passive ion diffusion, and (c) outline of the typical depolarization and repolarization process and time frame for the generalized action potential.

Activation energy, fission

[atomic] A CHEMICAL REACTION requires a minimum amount of KINETIC ENERGY that colliding MOLECULES allow to initiate a reaction. Once the reaction is in progress, it will release enough ENERGY to maintain the reaction.

Active transport

[biomedical] The transportation of MOLECULES with a mechanism of action that requires ENERGY to move the molecules against ELECTRICAL and/or CONCENTRATION GRADIENTS. The primary ENERGY source is ADENOSINE TRIPHOSPHATE (ATP), while LIGHT and ELECTRONS can also act as driving mechanism (see [Figure A.38](#)).

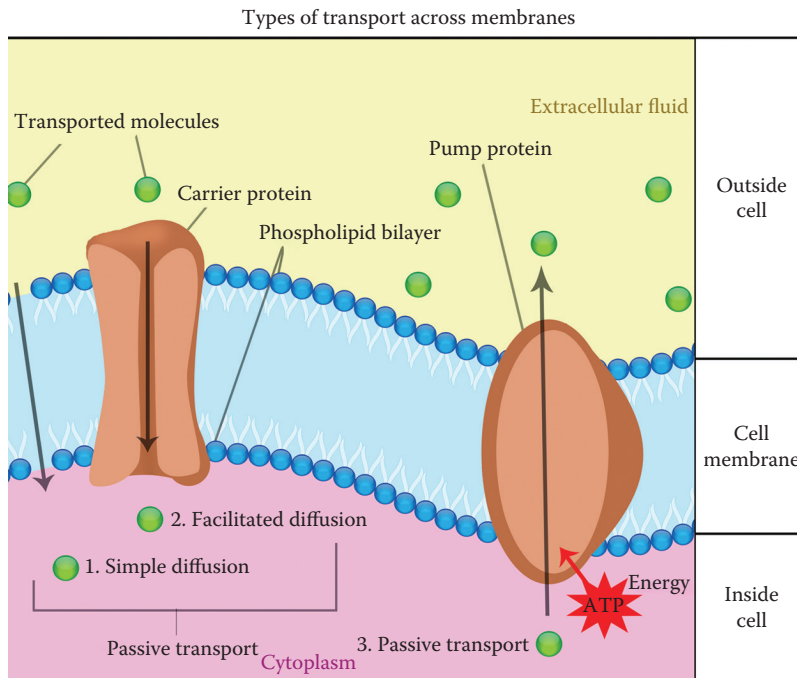


Figure A.38 The biological active transport of ions, nutrients and oxygen, and waste through the phospholipid bilayer cell membrane.

Active transport, primary

[biomedical] Transmembrane transportation by means of moving molecules, nutrition, and/or waste products by formation of “pockets” (vacuole) in the CELL MEMBRANE that under external ENERGY supply migrate from intra- to extracellular and vice versa. The transport processes are, respectively, called EXOCYTOSIS and ENDOCYTOSIS. Endocytosis can be separated in LIQUID “consumption” as PINOCYTOSIS and in particle-intake as PHAGOCYTOSIS.

Active transport, secondary

[biomedical] Assisted transmembrane transportation using the ENERGY released by one SOLUTE moving with the CONCENTRATION GRADIENT to move another solute against the concentration gradient. The transport can be parallel and matching to the driving gradient (i.e., cotransport or symport) or antiparallel (i.e., countertransport or anti-transport).

Activity

[thermodynamics] Coefficient of a constituent i in a mixture (γ_i) indicator of deviation of the characteristics of the components of a condensed AGGREGATION of a nonideal GAS MIXTURE operating as an IDEAL GAS from ideal behavior. The activity coefficient of the constituent i is defined as $\gamma_i = a_i/x_i$, where a_i is the activity of constituent i , and x_i is the molar fraction of the i th component of the mixtures expressed by Dalton's law: $x_i = P_i/P$ with P the total pressure of the mixture. The activity ties together with the chemical potential μ_i as follows: $\mu_i = \mu_{i0} + RT \ln x_i + RT \ln \gamma_i$, where R is the Boltzmann constant and T is the temperature.

Activity ($\alpha(T, P, P_0)$)

[thermodynamics] Derived from the interpretation of the ESCAPE TENDENCY within the CHEMICAL POTENTIAL: $\mu(T, P)$ of a MEDIUM operating under the IDEAL GAS LAW at certain TEMPERATURE (T) and PRESSURE (P) relative to a reference state at identical temperature but equilibrium pressure P_0 . The excess chemical potential with respect to the reference state is the activity, defined as $\alpha(T, P, P_0) = \exp\{[\mu(T, P) - \mu(T, P_0)]/RT\} = \pi(T, P)/\pi(T, P_0)$, where $\pi(T, P)$ is the FUGACITY, the chemical potential and R the Boltzmann constant.

Activity, defined (R_a)

[general, nuclear] Rate of generation of DECAY particles (i.e., RADIATION: dN_r) over a time span dt from a grouping of RADIOACTIVE NUCLEI: N during ISOTOPE degradation: $R_a = dN_r/dt = \lambda N = \lambda N_0 e^{-\lambda t}$, where λ is the decay constant. Commonly used units for ACTIVITY are BECQUEREL (Bq) (SI), Rutherford (R) and Curie (Ci) (non-SI) ($1 Bq = 1$ disintegration/s; $1 R = 1 \times 10^6$ disintegrations/s; $1 Ci = 3.70 \times 10^{10}$ disintegrations/s).

Activity, metabolic

[biomedical] See METABOLIC ACTIVITY.

Activity, molecular

[thermodynamics] The respective sum of the kinetic and potential ENERGY of the molecules.

Acute angle

[general] An ANGLE in a triangle on either ends opposite the right angle used to determine sine and cosine functions. The choice of the appropriate acute angle depends on the prevalent reference frame; generally, the sine provides the vertical segment, and the triangle can be flipped 180° for either acute angles.

Acute respiratory distress syndrome (ARDS)

[biomedical] Increase of the permeability of the endothelial MEMBRANE in the PULMONARY microvasculature. The transcapillary filtration pressure in the lungs, as subjected to STARLING FORCES based on respective OSMOTIC PRESSURES, reduces the oxygen exchange from alveoli to blood in addition to creating an imbalance in fluid exchange, potentially leading to chronic pulmonary hypertension.

Adaptive optics

[astronomy/astrophysics, biomedical, optics] A means or mechanism that provides compensation for transmission of artifacts resulting from distortions created by the transmitting medium, for example, compensation with regard to the Abbe diffraction limit. Generally, an electronic and mechanical feedback system using optical sensors (e.g., digital CAMERA) measuring PHASE aberrations drives an iterative adjustment to deformable OPTICS, either MIRROR or LENS, or both, in the imaging device configuration, eliminating

the detected aberrations. Corrections can be for atmospheric disturbances that generate discontinuities and gradients in the index of REFRACTION along the path of the observed light. Galactic distortions can, for instance, originate from dust clouds, magnetic and electric field lines, and thermal emissions, for example, stars (*also see* EYE) (see Figure A.39).



Figure A.39 Autofocusing targeting scope mounted on a rifle.

Adaptive time step

[computational, fluid dynamics] Various DIFFUSION ALGORITHMS and other DIFFERENTIAL EQUATIONS can exhibit multiple time scales. This requires the use of robust variable step-time integrators to efficiently solve for these conditions computationally. One computational approach is the use of the second-order TRAPEZOID RULE using an explicit method such as the Adams–Bashforth method. This allows for well-maintained error control. The trapezoid rule is nondispersive and stable, to commensurate with a second-order spatial discretization. The simplest Adams–Bashforth–Moulton pair is, for instance, readily available as a MATLAB® function. This approximation is particularly well suited for long-time integration. In the following approach, the incremental time steps increase to infinity at the end of the series. According to the trapezoid rule, the following vector approximation can be made: $\zeta_n \cong \zeta(t_n)$, implementing a time step Δt_n . The increment can be computed as $\zeta_{n+1} \cong \zeta(t_n + \Delta t_n)$ by solving the following implicit system: $\zeta_{n+1} = \zeta_n + (1/2)\Delta t_n (\dot{\zeta}_{n+1} + \dot{\zeta}_n) = \zeta_n + M^{-1} [f - (1/2)\mathcal{A}(\zeta_{n+1} + \zeta_n)]$, where $\mathcal{A}$ is the sum of a skew symmetric convection matrix and a symmetric positive-definite diffusion matrix, and $\mathcal{A}$ the mass matrix tied together by a system of coupled n th order ORDINARY DIFFERENTIAL EQUATIONS as $M\dot{\zeta} + \mathcal{A}\zeta = f$; $\zeta(0) = \zeta_0$. The adaptive time step function will have a truncation error defined by $\zeta_{n+1}^* = \zeta_n + \Delta t_n \dot{\zeta}_n + (1/2)\Delta t_n^2 [(\dot{\zeta}_n + \dot{\zeta}_{n-1})/\Delta t_{n-1}]$, which follows from the second-order Adams–Bashforth method.

Addition theorem for velocities

[atomic, mechanics, nuclear] In classical MECHANICS, velocities of the moving object and the moving reference frame with respect to a fixed point of reference can be added as vectors, adding the x - and y -components of the respective aspects of MOTION to be recombined as a resultant vector. This principle can readily be explained with the Galilei transform in which the coordinates moves as $x' = v'_x t'$ and $y' = v'_y t'$, because the time t in the reference frame may not be standard. This addition in the experiment of Fizeau requires the theoretical derivation to include the Lorentz transformations as well to account for velocity changes because of the medium (i.e., the local index of REFRACTION).

Additive coloration

[general, optics] Combination of colors creating new colors, such as that based on the red–green–blue (RGB) base three-primary COLOR set (trichromatic). The RGB system is used in television and PHOTOGRAPHY. In this configuration, all three colors combined yield WHITE LIGHT. Another color definition is the International Commission on Illumination (CIE) color space CHROMATICITY diagram, which was designed in 1931 (see CIE 1931 COLOR SPACE) (see Figure A.40).



Figure A.40 Color map used to illustrate the concept of additive color in illumination. Mind that in solid coloring, the additive concept works differently, because the perceived color is based on absorption, meaning white has no pigments in the surface of the observed object.

Additive process

[biomedical] In regenerative MEDICINE, the formation of SCAFFOLD structures can rely on additive and subtractive processes. The additive processes involve the assembly from fundamental structural building blocks (e.g., protein chains, including soy, and polymers) or monolayers, including mineralization that form during a “growth” process.

Additive property

[thermodynamics] Property that is subject to the superposition principle in a linear system. This applies to system properties describing the convolution of a mixture of two or more states of a single system. Examples are ENERGY and entropy. Additionally, physical parameters of constituents are additive, such as pressure, volume, and mass.

Additivity, of energy

[thermodynamics] See ADDITIVE PROPERTY. This principle is governed by the FIRST LAW OF THERMODYNAMICS.

Additivity, of energy differences

[thermodynamics] The total difference in ENERGY between two IDENTICAL STATES of two respective systems is equal to the sum of the differences of the individual systems.

Additivity, of entropy

[thermodynamics] With any change of state of a system the entropy (S_i) will remain constant (spontaneous—reversible process) or will increase (irreversible process), also called the “principle of non-decrease of entropy”: $S_1 - S_2 \geq 0$ (also see ADDITIVE PROPERTY).

Additivity, of entropy differences

A

[thermodynamics] The total entropy difference between two states of the individual components of a composite system is equal to the sum of the entropy differences of the respective constituents. A composite system C from constituents B and A with states 1 and 2 is expressed as follows:

$$S_{22}^C - S_{11}^C = (S_2^A - S_1^A) + (S_2^B - S_1^B).$$

Adenosine diphosphate

[biomedical] ADP is a chemical chain that is an integral part of the cellular renewable ENERGY supply through the chemical linking of one phosphate ION in the process of forming ATP (*see* ADENOSINE TRIPHOSPHATE) with the assistance of approximately 6.7 kcal/mol of energy. This energy is, for instance, supplied by the aerobic breakdown of GLUCOSE and fatty acids.

Adenosine triphosphate

[biomedical] ATP is a chemical chain that is an integral part of the cellular renewable ENERGY supply through the chemical release of one phosphate ion in the process of forming ADP (*see* ADENOSINE DIPHOSPHATE), producing approximately 6.7 kcal/mol of energy that is used in the cell's NUCLEUS for its METABOLISM as well as for MEMBRANE ACTIVITY such as "ACTIVE TRANSPORT." The exact amount of energy released depends on various cellular and environmental conditions. The chemical reaction transpires as follows: $\text{ATP} + \text{H}_2\text{O} \leftrightarrow \text{ADP} + \text{P}^+ 30543.2 \text{ J/mol}$ (*see* Figure A.41).

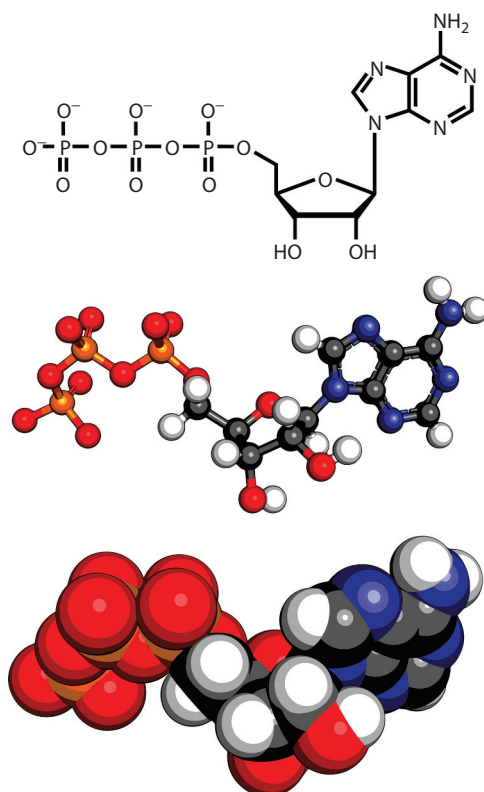


Figure A.41 Graphical representation of the adenosine triphosphate molecule.

Adhesion

[general, solid-state, thermodynamics] Chemical, electrostatic, or mechanical bond between two surfaces. The effect plays a significant role in producing FRICTION as a binding force between molecules of separate substances, or individual constituents of different nature (e.g., different materials). Contrast to COHESION (see Figure A.42).



Figure A.42 Adhesion has many commercial varieties, slow or fast curing. Illustrated is the adhesive power of chewing-gum “rubber” on the sole of a shoe.

Adhesion strength

[biomedical, chemical] Bonding strength (force per bond: f_a) between CELL and free surface based on LIGAND interaction. This concept was introduced in 1978 by GEORGE IRVING BELL (1926–2000) based on ligand “concentration” $[L]$ and a length parameter (γ_ℓ) derived from the association rate with rate constant $k_r = k_{r0} \exp(\gamma_\ell F / N_C k_b T)$ (under the influence of external force F , where N_C represents the receptor–ligand complexes and the Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ at temperature T) defined as $f_a = F/n_B \approx 0.7(k_b T / \gamma_\ell) \ln([L]/K_D^0)$, where K_D^0 is the dissociation rate constant without stress and n_B is the number of formed bonds. This principle can also apply to the mechanism of action supporting muscular contraction.

Adhesive work

[biomedical, thermodynamics] W_A is the strength of ADHESION to a SOLIDS (_s) surface, primarily used for LIQUIDS (_l) as expressed by SURFACE TENSION in $W_A = W_{sl} = \gamma_{sv} + \gamma_{lv} - \gamma_{sl} + \pi_e$, where the surface tension between the LIQUID and the liquid–vapor and solid and its VAPOR are represented by γ_{lv} and γ_{sv} , respectively, and the tension between the surface of the solid with the liquid is γ_{sl} . The VAPOR PRESSURE (π_e) of the liquid in contact with the surface in equilibrium as it flows out is usually negligible. This value can also be measured with a STRAIN-GAUGE or can be derived from the GIBBS ENERGY of ADHESION: $W_A = -G_A$.

Adiabat

[general, thermodynamics] The curve in the P – V diagram (pressure $[P]$ *vertically* against volume $[V]$ *horizontally* diagram) representing the changing conditions under ADIABATIC COMPRESSION of a gas. While compressing the gas, the work ($W < 0$) performed will increase the internal ENERGY ($\Delta U = -W$) (*Note:* CONSERVATION OF ENERGY principle), thus increasing the temperature (T). Because the Boyle–Guy–Lussac law

holds true for constant temperature when relating pressure to volume, the adiabatic compression deviates from the IDEAL GAS LAW represented by the “ADIABAT” curve (see Figure A.43).

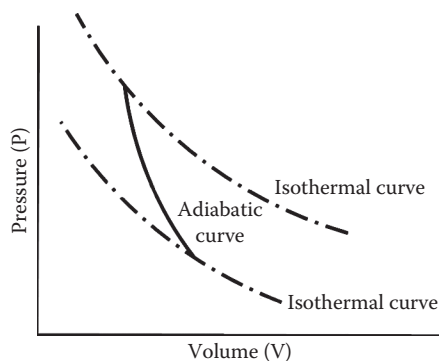


Figure A.43 Graphical representation of the adiabatic process transfer between two isothermal processes.

Adiabatic approximation

[computational, thermodynamics] It is also called “BORN–OPPENHEIMER APPROXIMATION.” The basic strategy is to first hold the external parameters fixed and solve for the behavior of the system. Next, allow the parameters to change at the end of the initial calculations. This may involve an iteration process to solve for the full initial to final transition. On an atomic level, the situation refers to solving for the WAVE functions of the nuclei and the electrons. In this case, an assumption is made that the electrons are much lighter than the nuclear constituents, in the range of 3 to 4 orders of MAGNITUDE. The lighter electrons that are bound in the POTENTIAL WELL of the nuclei move significantly faster than the heavy nuclei. The adiabatic approximation assumes that the electrons follow the nuclear constituents in their MOTION, and hence the electron wave function is coupled (*also see* BORN–OPPENHEIMER APPROXIMATION). Returning to the initial approach, the SCHRÖDINGER EQUATION and the resulting wave function and the associated VIBRATION frequency of the nuclei of a molecule can be obtained by assuming a nuclear dimension R . The value of R yielding the lowest total ENERGY can be derived while solving the electron eigenstate problem for fixed nuclei and subsequently calculating for this condition the net nucleus–nucleus force.

Adiabatic availability

[thermodynamics] Because the entropy affects the usefulness of the ENERGY of a system, the adiabatic availability is inversely proportional to the entropy. The adiabatic availability is the energy difference between the lowest EQUILIBRIUM STATE above the GROUND STATE of a system and the highest excited state.

Adiabatic change

[fluid dynamics, general, mechanics, thermodynamics] An IDEAL GAS can be subjected to a change in pressure or volume while preventing the exchange of heat with the surroundings, for instance, the rapid down stroke of a hand PUMP or the EXPANSION of a CO_2 or N_2O_2 container (e.g., fire extinguisher or whipped cream canister). The first situation results in a temperature rise whereas the second one yields a temperature drop, primarily because of the work applied on the system or by the system, respectively. An example in MECHANICS: a PENDULUM moving without FRICTION at constant and lossless MOTION has the length of the pendulum gradually lengthened, thus gradually changing the motion, which in this case is done adiabatically. The length is altered throughout the swinging process, not abruptly at, for instance, the highest point of the swing. A mechanical equivalent can be found in the elastic deformation of the length of a pendulum under tension, presumably because of MATERIAL FATIGUE.

Adiabatic compression

[thermodynamics] The compression of an IDEAL GAS under adiabatic conditions.

Adiabatic demagnetization

[general] Mechanism used in the attempt to attain the ABSOLUTE ZERO, on both a MACROSCOPIC scale and a nuclear scale. The temperature manipulation uses the magnetic orientation of the atomic and nuclear components. The temperature follows the mechanism $\Delta T = W_M / \rho c$, where W_M is the magnetic HYSTERESIS work per unit volume, ρ is the density, and c is the SPECIFIC HEAT. On a nuclear level, demagnetization is applied to the nuclear SPIN phenomena and to associated magnetic moments. The MICROSCOPIC magnetic moments result from the following mechanisms: ELECTRON SPIN and electron ORBITAL ANGULAR MOMENTUM, next to the elusive PROTON and NEUTRON spins. An externally applied alternating strong MAGNETIC FIELD applied under adiabatic conditions disorients the nuclear magnetic moments, which will fall back to their GROUND STATE by taking away from the internal ENERGY, thus reducing the temperature on a nuclear level. The nuclear adiabatic magnetization reaches the lowest temperatures so far (approximately $T = 2 \times 10^{-8}$ K).

Adiabatic expansion

[thermodynamics] The EXPANSION of an IDEAL GAS under adiabatic conditions.

Adiabatic flame temperature

[thermodynamics] Temperature of the flame products after the ignition of a combustible GAS that produces no work, nor is there an exchange of heat with the ambient environment.

Adiabatic process

[biomedical, general, thermodynamics] A process in which there is no exchange of HEAT. It is derived from the Greek word “adiabatos,” which translates as “not to be passed.” This condition is satisfied under one of two circumstances: INSULATION or THERMAL EQUILIBRIUM with the surroundings. This does not equate to ISOTHERMAL, because the INTERNAL ENERGY may still change due to WORK. An adiabatic process falls under the FIRST LAW OF THERMODYNAMICS. In an adiabatic process, however, no exchange or conversion of heat takes place, that is, no change of heat for acquisition or loss of MECHANICAL ENERGY.

ADP

[biomedical] See ADENOSINE DIPHOSPHATE.

Adsorption

[fluid dynamics, general, nuclear] It is similar to ABSORPTION but limited to SURFACE interaction only. This phenomenon is primarily the result of surface FORCES (chemical attraction) and frequently results in the MOLECULAR binding of a medium to an engulfing substance either in GAS form or in the form of SOLUTION. There is a direct correlation between the VAPOR PRESSURE of a LIQUID medium and the gas adsorption at the surface of the liquid. The basis of the attraction is the fluctuating ELECTRIC FIELDS of molecular DIPOLES and POLARIZED atoms under the influence of the surrounding bulk volume of constituent,

particularly the direct neighbors closest to the surface; these forces between neutral ATOMIC and molecular substances are grouped under VAN DER WAALS FORCES (see [Figure A.44](#)).

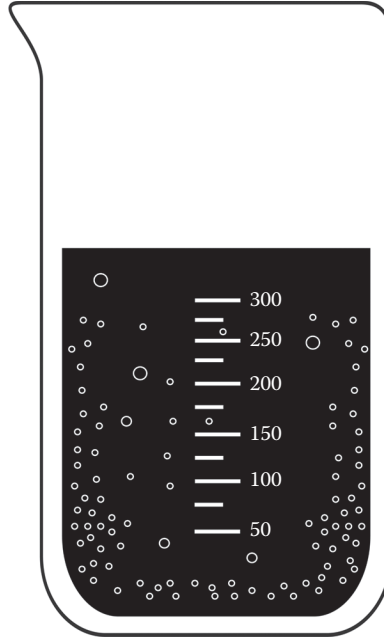


Figure A.44 Artist impression of the molecular exchange at the interface between two media.

Aeolian tones

[acoustics, fluid dynamics, mechanics] SOUND made by wires in the wind resulting from KÁRMÁN EDDY CURRENT VORTEX STREET formation—very familiar sounds on a sailboat under strong wind. Placing a taught wire between the thumb area of two hands pressed together only at the thumbs and ball of the hand (as “in prayer”) will leave a small gap that when blowing on the wire will create AEOLIAN TONES (practice and skills required). More specific and everyday examples are the wind rushing past cables under tension or obstructions (*also see* TACOMA NARROWS BRIDGE) (see [Figure A.45](#)).

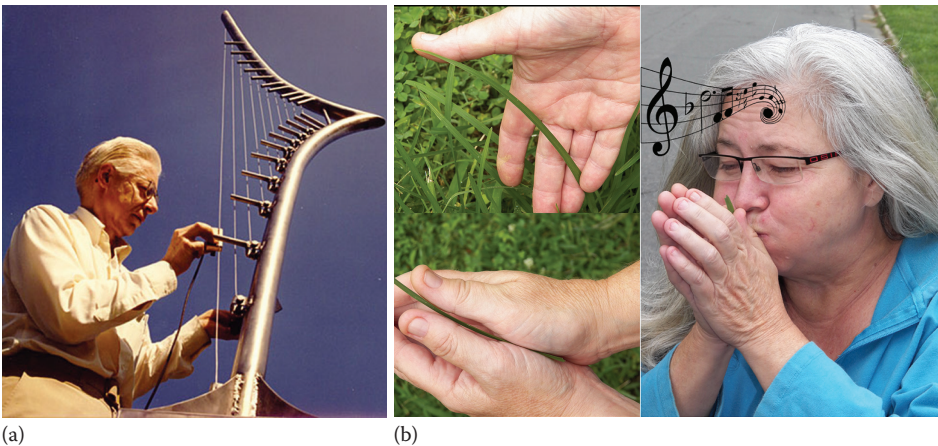


Figure A.45 (a) Aeolian harp. (b) It is also possible to make sounds with a blade of grass under tension between the thumbs.

Aerodynamics

[fluid dynamics, general, mechanics] The study of the relative MOTION of fluids, particularly gaseous substances around objects with the inherent forces. This field of ENGINEERING evaluates the forces acting on the object because of the gaseous FLOW or the respective motion of the object as well as the motion artifacts with the flow pattern, such as TURBULENCE, DRAG, LIFT, and velocity-layering effects (i.e., VISCOSITY), as a function of the flow in proximity to the object. The shape and size of the object and relative motion are also part of the theoretical analysis in regard to the following fluid-dynamic dimensionless parameters: Brinkman number, Bond number, DEAN NUMBER, Eckert number, GRASHOF NUMBER, MASS TRANSFER Biot number, Prandtl number, REYNOLDS NUMBER, Strouhal number, and Weber number. Other aspects include sound, MACH NUMBER, and sonic/supersonic classification (*also see* COMPUTATIONAL FLUID DYNAMICS) (see Figure A.46).

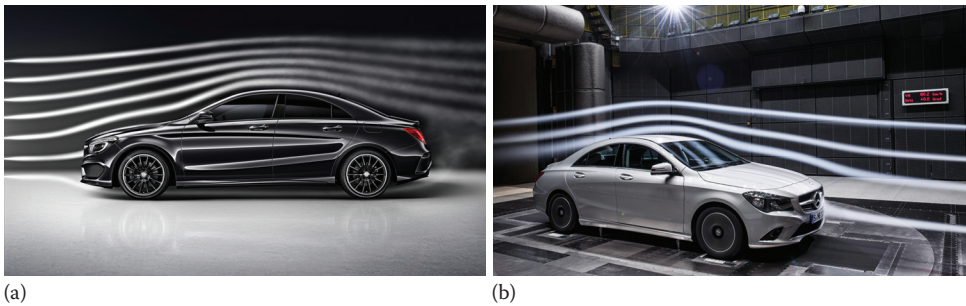


Figure A.46 (a) Streamlines of the air-flow pattern for a Mercedes CLA (Courtesy of Daimler AG.), the production automobile with the lowest coefficient of air friction at the time of this publication ($C_d = 0.23$). Note that Formula 1[®] race cars are unique, single production vehicles and have a much lower coefficient of friction and (b) different perspective of flow dynamics for Mercedes CLA automobile. (Courtesy of Daimler AG.)

Aerofoil

[fluid dynamics] *See* AIRFOIL.

Aerofoil section

[fluid dynamics] WING cross-sectional designs. A wing may be constructed with several AEROFOIL sections, blending into each other to maximize the AERODYNAMICS. The structural behavior of the aerofoil can be analyzed based on a model that allows for linear bending as well as torsional springs with inherent dampeners that can be assumed to be attached to the elastic axis of the aerofoil. The mechanical parameters are captured as the mass (m), the static moment about the elastic axis (S_α), a DAMPING coefficient for the TORSION (plunge) (c_b), and stiffness coefficient in plunge (K_b), next to the moment of INERTIA with respect to the total wing-mass (I_α) in reference to the elastic axis, with a torsional damping constant (c_α), and torsional rigidity (stiffness coefficient K_α), where the plunge deflection with respect to the elastic axis is b , and α is the PITCH

ANGLE in the direction of nose-up tilting around the elastic axis. The LIFT (F_L) for FLUID with density ρ can be defined as $-F_L = m(d^2b/dt^2) + S_\alpha(d^2\alpha/dt^2) + c_b(db/dt) + K_b b = -(1/2)\rho U^2 c C_{F_L}(\alpha, \dot{\alpha}, \ddot{\alpha}, \dot{b}, \ddot{b})$, respectively, where $\dot{\alpha} = d\alpha/dt$, $\ddot{\alpha} = d^2\alpha/dt^2$, $\dot{b} = db/dt$, $\ddot{b} = d^2b/dt^2$. The static moment with respect to the elastic axis (I_T) is described by $I_T = S_\alpha(d^2b/dt^2) + I_\alpha(d^2\alpha/dt^2) + c_\alpha(d\alpha/dt) + K_\alpha\alpha$, for an aerofoil with chord-length c , with midpoint $b = c/2$. The laminar horizontal FLOW velocity is U (also see **KUTTA-JOUKOWSKY LAW**) (see [Figure A.47](#)).

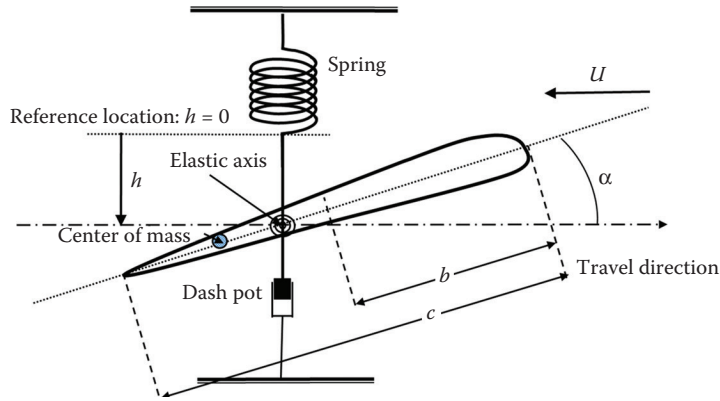


Figure A.47 Graphical representation of the mechanisms involved in the operation of an aerofoil, such as the wing of a plane.

Aerosol

[biomedical, fluid dynamics] It is the suspension of submicroscopic particles in a gaseous volume. Aerosols can be natural, for example, volcanic dust, histamines, and sea SALT, or man-made (anthropogenic), for example, drug (inhaler) and soot. Aerosols can act as condensation nuclei by providing a catalyst for RAIN generation and fog formation (see [Figure A.48](#)).



Figure A.48 The use of aerosols in paint, hair spray, cooking oil, and a large variety of other applications.

Aerostatics

[fluid dynamics, general, mechanics] Study of the equilibrium in fluids, coinciding with hydrostatics, with the main difference that aerostatic gasses are compressible fluids whereas liquids are not (see [Figure A.49](#)).



Figure A.49 Representation of static volume of enclosed gas used in an advertising “blimp,” according to the earlier concept of the Zeppelin, designed by Graf Ferdinand von Zeppelin (1838–1917) from the Prussian Empire/Germany.

Aether

[general, geophysics, optics] (*also* ETHER) The medium initially assumed to be the means for transmittance of ELECTROMAGNETIC RADIATION (ARISTOTLE [384–322 BC]), later reiterated by Christiaan Huygens. Initially, ARMAND HIPPOLYTE LOUIS FIZEAU (1819–1896) concluded that the aether concept does not hold true for light passing through a wavy water surface; there is a lag in the propagation pattern, primarily because of REFRACTION. The aether concept was formally disproved with the MAXWELL EQUATIONS, describing the transport of ENERGY without the need for a CARRIER substance and allowing for transmittance through VACUUM. This is in contrast to ACOUSTIC WAVES mandatorily traveling in a mechanical medium composed of solids, liquids, gases, and/or PLASMA.

Affinity of a chemical reaction mechanism (Y_j)

[thermodynamics] Indication of PROBABILITY to initiate a chemical reaction, for example, binding, ELECTRON RELEASE, and establishing chemical matrix configuration (e.g., diamond pattern). The probability in turn is directly linked to the ENTROPY of the STATE of the SYSTEM. Under CHEMICAL EQUILIBRIUM, the “affinity” is zero for each respective REACTION MECHANISM. The affinity expression for the respective reaction mechanisms (indicated by the order number j is defined as the partial derivative of the entropy (S_ϵ) as a function of the respective (chemical-) REACTION COORDINATES (ϵ_j): $Y_j = (\partial S_\epsilon / \partial \epsilon_j)_{U,V,n_a,V,\epsilon} = \sum_{i=1}^r (\partial S_{\text{off}} / \partial n_i)_{U,V,n} (\partial n_i / \partial \epsilon_j)_{n_a,V,\epsilon} = -\sum_{i=1}^r (\mu_i / T) \nu_i^{(j)}$, where S_{off} indicates the entropy of a stable equilibrium condition where all reactions and interactions are turned off, n the respective amounts of the contributing r constituents of the medium, with internal ENERGY U and volume V , and the respective constituents each have a chemical potential μ_i , at temperature T , the coefficient $\nu_i^{(j)}$ indicates the STOICHIOMETRIC parameters at each state.

AFM

[biomedical, general, nuclear, solid-state] See ATOMIC FORCE MICROSCOPE.

Age

[nuclear] The lifetime, from inception to age, can be determined from ISOTOPE DECAY using the HALF-LIFE of specific ELEMENTS. There is, however, a distinct difference between the RADIOACTIVE years and the calendar years. This distinction comes from the fact that all dating assumptions need to be satisfied and ideally backed-up with historical data (recent human history, ancient Greek and Arabic records). The choice of the ELEMENT by definitions limits the time range and level of accuracy to determine the age of an object containing a specific NUCLEAR reactive group of ATOMS (see RADIOACTIVE DATING). For instance, the rate of DECAY of carbon-14 has a HALF-LIFE of 5,730 years, and in naturally occurring CARBON, there is one ^{14}C ATOM for every trillion ^{12}C atoms. However, at a certain point in time, the chance of decay has decreased to one event per hundreds (-thousands?) of years, so you either measure this decay event or you do not; hence the time limit for accurate CARBON DATING is approximately 70,000 years, depending on the measuring

technique and quality of the devices. At 40,000 years, the background RADIATION starts to play a significant role when not properly accounted for or shielded against. Hence, taking the proper precautions in determining the age of an object is critical.

Age of the earth's crust

[atomic, nuclear] The EARTH'S CRUST has solidified over time in location and ranges in thickness from 20 km to close to 70 km. Typically, the age of the earth's crust is split on geological phenomena as in younger than 30 million years and older than 30 million years ($\sim 3.0 \times 10^7$ years). In comparison, the EARTH is believed to have formed 4.54 billion years ago (4.54×10^9 years $\pm 1\%$) based on Uranium dating. In reference, the AGE of the MILKY WAY is currently estimated at 11 to 13 billion years (1.2×10^{10} years $\pm 10\%$) (see [Figure A.50](#)).



Figure A.50 Continental drift was first hypothesized in 1596 by Abraham Ortelius (1527–1598) from Belgium/the Netherlands (painting by the Belgian master Peter Paul Rubens). The concept was verified and validated by Alfred Wegener (1880–1930) from Germany in 1912.

Aggregation

[general, thermodynamics, solid-state] State of aggregation, *see* PHASE (of medium): the condition in which a medium or substance presents itself: solid, LIQUID, or GAS. This means “the conglomeration to one whole.” However, the aggregation generally refers to a broader range of material characteristics. In general, a phase (e.g., gas, liquid, solid, PLASMA, superfluids, supersolids, and Bose–Einstein condensates) consists of a single form of aggregation, whereas a form of aggregation may consist of a mixture of several phases, or can be the NONEQUILIBRIUM STATE of a medium. One such example of aggregation states is the hydrophobic or hydrophilic aggregation of solid particles in a SOLUTION. For instance, in a non-wetting medium during hydrophobic aggregation, gas cavities have been observed between the solid and the liquid (see [Figure A.51](#)).

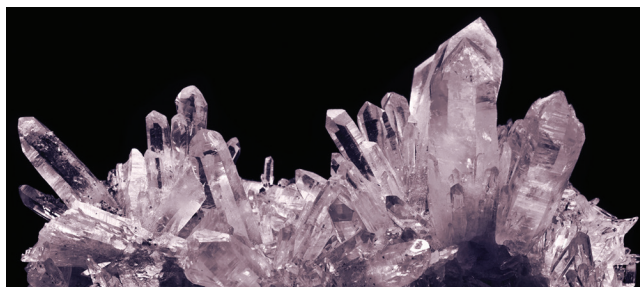


Figure A.51 Quartz aggregate.

Agonist

[biomedical] Molecule that facilitates a chemical bond formation while attached to a soluble factor consisting of proteins pertaining to mediation of CELL actions and cell growth.

Air

[general] Atmospheric GAS MIXTURE composed of the following constituents on a MOLE basis, excluding water VAPOR: nitrogen (N_2 , 78.08%), oxygen (O_2 , 20.95%), argon (Ar, 0.94%), carbon dioxide (CO_2 , 0.03%), Hydrogen (H_2 , 0.01%), neon (Ne, 0.0015%), helium (He, 0.00015%), and other TRACE gasses depending on location, altitude, and weather conditions such as sulfur products, methane, krypton (Kr), nitrous oxide (N_2O), xenon (Xe), and ozone (O_3). The average MOLECULAR WEIGHT of atmospheric air is $M_{air} = 28.964 \times 10^{-3}$ kg/mol. Dry air may be considered an IDEAL GAS, with specific heat ration $\gamma_{air} = 1.4$ and SPECIFIC HEAT under constant pressure $c_{p_air} = \gamma_{air} (R/M_{air}) (\gamma_{air} - 1) = 1.4 [8.314 / (28.964 \times 10^{-3})] 0.4 = 1 \text{ kJ/kg K}$, with the universal gas constant $R = 8.314 \text{ J/mol K}$.

Air bubble method

[fluid dynamics] The release of air bubbles under upward FLOW conditions used to determine the flow velocity of the LIQUID. The preferred mechanism is the hydrogen bubble. The DISTANCE per unit time of the air bubble can provide a noninvasive mechanism for flow control measurements. Other applications are in velocity profiling. Competitive techniques include the smoke wire method and the spark tracing method.

Air capacitor

[general] CAPACITOR that uses an air-gap as an INSULATOR between the two POLES of the capacitor. This type of capacitor was widely used in AM and FM RADIO devices in the late twentieth century (see [Figure A.52](#)).

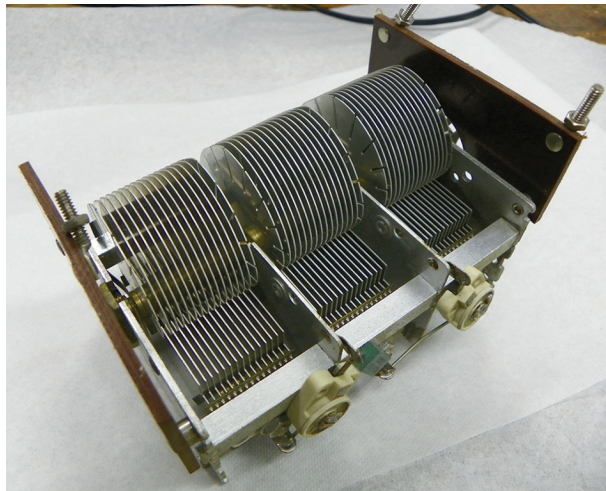


Figure A.52 Capacitor plates with air gap that can change the opposing surface area by means of turning a dial. This type of air-capacitor was used in the early design radio for tuning purposes, changing the resonant frequency by changing the capacitor value in the electronic resonator.

Air columns

[general] Wind instruments use standing waves in air columns as a means to amplify the generation of SOUND due to RESONANCE effects. The creation of a standing WAVE in an air column has to satisfy a multiple of quarter or half wavelengths depending on whether the column is closed on one end or open on both ends

(e.g., pan flute). The length of the column is frequently controlled by vents in the side of the column that are closed off by fingers (e.g., straight flute) or mechanical keys and levers (e.g., saxophone) (see [Figure A.53](#)).



Figure A.53 The saxophone is one of many instruments that generate musical tones that can be modified by changing the length of the air-column, as illustrated by President William (Bill) Jefferson Clinton (1946–) playing the saxophone in the dacha of the president of the Russian Federation Boris Yeltsin (1931–2007) in 1994. (Courtesy of Bob McNeely, William J. Clinton Presidential Library, Little Rock, Arkansas.)

Air drag

[computational, fluid dynamics] See **AIR FRICTION**.

Air friction

[general] Resistive **FORCE** associated with movement through **AIR**. The resistive force experience by the object is proportional to the relative **VELOCITY** (v), the density of the medium, the exposed area normal to the direction of **MOTION** as well as the surface shape and the associated **REYNOLDS NUMBER** next to the surface finish/treatment. All of the latter conditions can be captured as a constant, assuming no change in density (b): $F_r = -bv$. Using the sum of forces $\sum F = F_{\text{driving}} - bv = ma = m(dv/dt)$, the velocity approached the limit of the **TERMINAL VELOCITY** when the resistive force approach the driving force for motion, during the downward free fall, this force would be the **WEIGHT** (F_g) of the object with mass m under **GRAVITATIONAL ACCELERATION**: g ($F_g = mg$) which yields $dv/dt = g - (b/m)v$. Under high-speed movement through air, the approximation for the resistive force becomes proportional to the square of the velocity, such as for airplanes (frequently well in excess of 600 km/h), sky divers (200–300 km/h), baseballs (>150 km/h), and, in some instances, cars: $F_r = -(1/2)\rho D A v^2$, where A is the cross-sectional normal area of the moving object measured in a plane perpendicular to its velocity, ρ is the **DENSITY** of air, and D is the **DRAW COEFFICIENT** (coupled to the Reynolds number), a dimensionless empirical quantity. Spherical objects for instance will have a drag coefficient of approximately 0.5 for but can have a value as large as 2 for objects that are flat or irregular. The theoretical approach predominantly relies on the assumption that the object motion and the **FLOW** of air (i.e., relative velocity) is in the same one-dimensional orientation; however, in practice, this may not always be satisfied. Because of differential dependencies, solving this type of practical problem will require the use of the **EULER METHOD**.

Airfoil

[general] An object with a specific shape that is designed to create a **LIFT** action when exposed to **FLUID FLOW** (**GAS** or **LIQUID**). The lift is the result of the Bernoulli principle, for example **WING**, sail, and ski-jumper in free flight (see [Figure A.54](#)).



Figure A.54 (a) Typical airfoil: airplane wing. The streamlines with respect to the wing surface can be modified to influence the lift by (b) opening and (c) closing the “flaps” at the wing tip.

Air–fuel ratio

[energy, thermodynamics] An EXOTHERMIC REACTION is the OXIDATION of a reactant such as hydrogen and fossil fuels, that is, gasoline and coal, combined in a COMBUSTION mechanism of action. The smallest amount of dry AIR (STOICHIOMETRIC amount) needed for a self-sustained combustion is calculated theoretically based on the chemical binding between the constituents of the hydrocarbon as $C_k H_l + kO_2 + (l/4)O_2 = kCO_2 + l(1/2)H_2O$, which brings the oxygen ($[n_{ox}]$) to fuel ($[n_{fuel}]$) molar ratio to $n_{ox}/n_{fuel} = k + (l/4)$, after considering the molar fraction of 20.95% oxygen in air, the molar fraction of oxygen in dry air yields $1 \text{ mol } [O_2] = 4.77 \text{ mol } [\text{air}]$, and hence the ideal theoretical air-fuel mixture for fossil fuel is $(n_{air}/n_{fuel}) = 4.77[k + (l/4)]$, or based on mass $(m_{air}/m_{fuel}) = 4.77[k + (l/4)](28.96/M_{fuel})$, where M_{fuel} is the MOLECULAR WEIGHT of the hydrocarbon fuel.

Airy, George Biddell (1801–1892)

[general] He is an English astronomer and mathematician. Airy helped establish GREENWICH as the prime meridian. Other work included the mathematical description and validation of PLANETARY ORBITS and the determination of the mean density of EARTH using a PENDULUM method. Airy’s work involved the planetary forces and mathematical description of the PLANETARY MOTION in the SOLAR SYSTEM, providing detailed NUMERICAL values of unprecedented accuracy in his time (see [Figure A.55](#)).



Figure A.55 George Biddell Airy (1801–1892), picture taken in 1891.

Airy disk

[general, optics] DIFFRACTION LIMITED IMAGE of a LIGHT SOURCE through a circular APERTURE. ELECTROMAGNETIC RADIATION passing through an aperture will experience IMAGE formation influenced by PHASE differences in the secondary sources of the ORIFICE area creating a FRAUNHOFER DIFFRACTION pattern. The central bright round projection is referred to as the “AIRY DISK,” the edge of the disk, or first minimum in the INTERFERENCE pattern is at an ANGLE with the normal to the orifice expressed as $\theta \approx \sin \theta = 1.22(\lambda/D)$, where λ is the wavelength and D is the diameter of the aperture. This diffraction pattern is the main limitation in RESOLUTION for most image formation devices as described by the RAYLEIGH CRITERION or ABBE CONDITION (see [Figure A.56](#)).

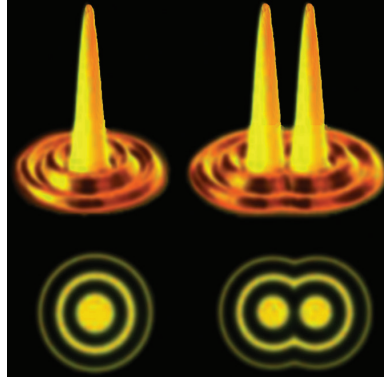


Figure A.56 Radiance pattern for an diffraction pattern Airy disks and the mechanism to distinguish adjacent points when the maxim of the Airy pattern of one object falls at least at a distance of the first minimum of the Airy disks of the other object viewed by the device limited in resolution based on its design.

AIS (abbreviated injury scale)

[biomedical] Injury-scale severity developed by the American Medical Association (AMA) and the American Association for Automotive Medicine (AAAM) to rank the physical damage to bone and mechanical performance as well as soft-tissue and related internal injuries. The ranking will guide the treatment procedure and the assessment of tolerance and assigning a tolerance curve to quantitative data. For physical trauma, the tolerance curve groups the level of injury with respect to the applied FORCE and the duration of the force. This guide is also used in the evaluation of the effectiveness of personal safety features and devices such as seat belts, AIR bags, and helmets.

Al-Bīrūnī (Abū al-Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī) (973–1048)

[general] Philosopher and scientist in the Persian Empire, from what is now known as a geographic section split between Uzbekistan and Turkmenistan. His contribution includes the principles of experimental investigation in MECHANICS (empirical/heuristic approach), and he introduced an EXPANSION on the ARCHIMEDES PRINCIPLE to introduce the RELATIVE DENSITY, a dimensionless parameter to describe MASS.

Albumin

[biomedical] Protein (MOLECULAR WEIGHT of 75,000) with average size of 700 nm. Albumin can contribute to the intra- and extracellular OSMOTIC PRESSURE, based on the VAN'T HOFF EQUATION (Starling equation). The CAPILLARY REFLECTION coefficient (Staverman reflection coefficient) for albumin is 0.8, meaning low permeability. However, a low protein diet may damage the vascular permeability, causing the WALL to leak out and filling the extra-cellular space with LIQUID because of the distortion of the hemodynamic and osmotic balance in the body.

Alcohol

[chemical] CARBOHYDRATE chain with hydroxyl group ($-\text{OH}$).

Alfvén, Hannes Olof Gösta (1908–1995)

[astronomy/astrophysics, computational, electromagnetism, fluid dynamics, mechanics, plasma] An engineer and physicist from Sweden who started out in electrical ENGINEERING. Alfvén received the Nobel Prize in Physics in 1970 for his work on magneto-hydrodynamics. The waves in a fluidic magnetic system known as magneto-hydrodynamic waves, also referred to as “Alfvén waves.” Hannes Alfvén is also known as the father of the concept of plasma PHYSICS. His work contributed substantially to the current understanding of the earth’s MAGNETOSPHERE, revealing many new aspects. Other efforts were in the description of LIGHTNING bolts as part of the general concepts of the mobility of charge particles in free space (see Figure A.57).



Figure A.57 Hannes Olof Gösta Alfvén (1908–1995) from Sweden.

Alfvén number ($A_L = (v_{\text{fluid}}/v_a)$)

[astronomy/astrophysics, computational, fluid dynamics, geophysics, mechanics] A dimensionless number used in flowing molten substances, where $v_a = (B_0/\sqrt{\mu_{\text{mag}}\rho})$ is the ALFVÉN VELOCITY and v_{fluid} is the FLUID FLOW velocity (*also see* MAGNETIC MACH NUMBER).

Alfvén theorem

[astronomy/astrophysics, computational, fluid dynamics, mechanics] Perfectly conductive fluids confined by a cylindrical configuration of a MAGNETIC FIELD will remain for eternity within the magnetic field lines. This applies to PLASMA eruptions from a STAR, resulting in a steady-state FLUX being emitted from the star.

Alfvén velocity ($v_a = (B_0/\sqrt{\mu_{\text{mag}}\rho})$)

[fluid dynamics, geophysics] The velocity of FLOW of a magnetic FLUID (e.g., magma and interstellar GAS) under the influence of an external MAGNETIC FIELD, where B_0 is the magnetic field strength, μ_{mag} is the magnetic permeability, and ρ is the density.

Algebra

[computational] Elementary mathematics based on the four concepts of addition, subtraction, multiplication, and division. Because of the limited principles, the concept of “limit” in range of numbers is not in the algebraic vocabulary. In “modern algebra,” the concept of letters representing numeric variables was introduced as an EXPANSION.

Alhazen (Abū ‘Alī al-Ḥasan ibn al-Ḥasan ibn al-Haytham) (965–1040)

[general, optics] An Iranian philosopher who introduced most of the formal scientific methods (i.e., validation of experimental observation by testing a hypothesis), especially in OPTICS. He is the founder of analytic geometry, applying ALGEBRA to geometry. He established the rudimentary workings of the EYE and disputed the long-standing theory that light is emanating from the eye to facilitate VISION as postulated by PTOLEMY (90–168 AD) and EUCLID (325–270 BC). In his book *Kitab al-Manazir* (*Book of Optics*), he reportedly described the observed injuries to the RETINA of the eye resulting from exposure to direct sunlight (see [Figure A.58](#)).



Figure A.58 Graphical interpretation of the likeness of Alhazen (965–1040) from Persia/Iran.

Aliasing

[computational] SIGNAL distortion resulting from signal-processing techniques, generally referring to the loss of acuity and discrimination between two independent signals that are acquired simultaneously.

Alkali metal

[general] First column of the PERIODIC TABLE OF ELEMENTS. ELEMENT with one unpaired electron; this electron is easily shared or released making the alkali metals a very chemically active group and are rarely found as a single element in nature. Because alkali metals are highly electropositive, they have the lowest IONIZATION enthalpies in the periodic table; ionization instantaneously provides them with the inert-gas electron configuration (most stable). The alkali-metal elements in this first column are LITHIUM (Li, 3 electrons; [He]2s¹, where [He] is the basis for the configuration of the inner electrons), SODIUM (Na, 11 electrons; [Ne]3s¹), POTASSIUM (K, 19 electrons; [Ar]4s¹), rubidium (Rb, 37 electrons; [Kr]5s¹), caesium (Cs, 55 electrons; [Xe]6s¹), and Francium (Fr, 87 electrons; [Rn]7s¹). Hydrogen (H; 1s¹) has only one electron but is always paired with hydrogen and is not considered an alkali metal. All alkali metals react strongly with halogens and form salts, and

interaction with WATER (H_2O) gives alkaline hydroxides. Other potential but unconfirmed alkali metals are ununennium (element $Z = 238$) and unhexennium (element $Z = 338$).

Alkaline earth metals

[general] Second column of the PERIODIC TABLE OF ELEMENTS. They are elements with two unpaired electrons: beryllium (Be, 4 electrons; $[\text{He}]2s^2$, where $[\text{He}]$ is the basis for the configuration of the inner electrons), magnesium (Mg, 12 electrons; $[\text{Ne}]3s^2$), calcium (Ca, 20 electrons; $[\text{Ar}]4s^2$), strontium (Sr, 38 electrons; $[\text{Kr}]5s^2$), barium (Ba, 56 electrons; $[\text{Xe}]6s^2$), and radium (Ra, 88 electrons; $[\text{Rn}]7s^2$ —unstable and radioactive). All alkaline earth metals react strongly with halogens and form salts.

Alkaloid

[chemical] Base, nonacid.

Allievi, Lorenzo (1856–1941)

[fluid dynamics] He is an electrical engineer and HYDRAULICS expert from Italy. Allievi provided a detailed hydrodynamic analysis of the WATER HAMMER effect, which caused catastrophic damage to the hydroelectric power plant at his work location in Papigno (see [Figure A.59](#)).



Figure A.59 Lorenzo Allievi (1856–1941) from Italy.

Allievi's equation, valve closure

[fluid dynamics] This equation applies to the pressure ratio between the closed-valve position and the open tube, however, only when the valve-closing time t_c is considered slow or $t_c > 2l/v_s$, where l is the length of the PIPE from the reservoir (or section with virtually unlimited free flowing LIQUID) to the VALVE, and $v_s = \sqrt{(K/\rho)/[1 + (D/b)(K/E)\text{const}]}$ the speed of WAVE propagation (e.g., SOUND) in the liquid with the liquid FLOW density ρ , K the bulk modulus of the liquid with regard to compressibility, D the inside diameter of tube with wall-thickness b , E the Young's modulus of the flexible pipe, and const is the correction factor for dimensional and material factor affecting the speed of sound. Under this condition, the pressure ratio can be derived as $P_{\max}/P_0 = 1 + (1/2)(n^2 + n\sqrt{n^2 + 4})$, where $P_{\max}$ is the highest pressure generated when the valve is closed, P_0 is the pressure in the pipe when the valve is open, $n = \rho l v_f / P_0 t_c$ and v_f is the flow VELOCITY (open valve). The equation does not take FRICTION into consideration and is ideal under all other circumstances.

Allotropy

[mechanics, solid-state] The phenomenon describing the changes in crystalline structure of specific materials under the influence of changing pressure or temperature. Another factor that can attribute to the final

configuration of the crystalline structure is material preparation. The ELEMENTS most known for allotropy are carbon, IRON, and sulfur, with carbon being most known for the difference between graphite and diamond. The allotropy of the crystalline configuration can be identified by either a thermodynamically stable or a metastable structure.

Allowed beta transition

[nuclear, solid-state] RADIOACTIVE DECAY with BETA PARTICLE release where zero ORBITAL ANGULAR MOMENTUM is ejected. The DECAY constant decreases approximately proportional to the fifth power of the decay ENERGY under this condition. This phenomenon was described by Enrico Fermi in 1934. The allowed beta decay is captured under the condition: $L_\beta = 0$, where L_β is the nuclear orbital angular momentum for beta decay: $L_\beta = M_\beta v_t r$, with v_t the tangential component of the velocity, and M_β the mass of the beta PARTICLE at orbit radius r .

Allowed transition

[atomic, energy, mechanics, nuclear, quantum, solid-state] Transition between two ENERGY states of the ATOM with emission of potentially a PARTICLE or otherwise ELECTROMAGNETIC RADIATION. RADIOACTIVE DECAY transitions of atomic nuclei are exempt from exclusion rules and have a high PROBABILITY of occurring. For emission of electromagnetic RADIATION, two sets of rules apply: conservation of ELECTRON SPIN quantum number $\Delta m_s = 0$, or the fact that the TOTAL ANGULAR MOMENTUM change must be one $\Delta j = \pm 1$, because the PHOTON has an intrinsic angular momentum of 1. The atomic transitions supporting the photon emission and angular momentum exchange are supported by the DIPOLE MODEL for the electrons in orbit around the NUCLEUS. For particle emission, one additional rule is added: $\Delta j = 0$ with the exception of a transition from $j = 0$ to $j = 0$. The transition also satisfies the CONSERVATION OF ENERGY law which entails that the wavelength of the emitted or absorbed light matches the energy difference between the two states of the atom. Also, under certain conditions (*Note: FLUORESCENCE*) there must be a change in PARITY, which translates in that the following WAVE EQUATION condition must be satisfied for the density of states (LAPORTE RULE, transition momentum integral): $\iiint \Psi_f^* \Delta V \Psi_0 dx dy dz \neq 0$, where Ψ_f^* is the complex conjugate WAVE FUNCTION of the final state, Ψ_0 is the initial state, and ΔV is the change in potential energy or the interaction potential. The wave function can be found by solving the SCHRÖDINGER EQUATION. For instance, during beta decay, the parity change is $\Delta \pi_p = (-1)^{L_\beta}$ and the PARITY CONSERVATION RULE accounts for this as $\pi_p = \pi_D (-1)^{L_\beta}$.

Alpha decay

[atomic, general, nuclear, quantum, solid-state] (syn.: ionizing radiation) {use: biomedical, fundamental} Release of ALPHA PARTICLE (α) emitted from the NUCLEUS of primarily heavy atoms (isotopes). The accompanying change in atomic number of the parent has a release of ENERGY involved difference in REST MASS (nonrelativistic: $E = mc^2$) between the parent and the “offspring,” also DISINTEGRATION ENERGY or ALPHA DECAY ENERGY (Q_d , expressed in MeV). The relationship between the DECAY time, or HALF-LIFE ($\tau_{1/2}$), and the decay energy was derived by JOHN MITCHELL NUTTALL (1890–1958) and JOHANNES WILHELM GEIGER (1822–1945) in 1911 is $\log(\tau_{1/2}) \cong \left(aZ/\sqrt{Q_d}\right) + b$, with for heavy nuclei $a = 1.454$ and $b = -46.83$ constants, and the decay time depends on the atomic number (Z). The alpha decay process can be described energetically as if the alpha particle is TUNNELING through a POTENTIAL BARRIER of Coulomb forces, both attractive and repulsive (also see QUANTUM MECHANICS OF ALPHA DECAY). An alpha particle released from a large ATOM by overcoming a significant BINDING ENERGY, which can be represented as a barrier. The barrier tunneling effect is illustrated in the figure below. Uranium-238 has a decay series that contains several steps where alpha particles are emitted. An alpha particle released from a large atom by overcoming a significant binding energy, which can be represented as a barrier. The barrier tunneling effect is illustrated in the figure.

Alpha decay barrier penetration

[atomic, general, nuclear, quantum, solid-state] Because the ALPHA PARTICLE is released from the NUCLEUS, it will need to penetrate a POTENTIAL BARRIER, that is $V = 2eZ_D(e/r)$, as free particle because the ENERGY of the alpha particle is less than the BINDING ENERGY. For instance, in an ATOM with atomic number $Z = 90$, the NUCLEAR BINDING ENERGY is greater than 8.6 MeV, whereas the alpha particle carries approximately 4.87 MeV. The attractive forces are both Coulomb and nuclear, which forms a POTENTIAL WELL. This TUNNELING can be accounted for with the QUANTUM THEORY. The PROBABILITY of alpha escape (λ_α) is proportional to the number of collisions with the WALL of the potential well, multiplied by the probability of the PARTICLE escaping the well (classical MECHANICS): $\lambda_\alpha \approx (v_{in}/R)P$, where v_{in} is the velocity of the alpha particle in the nucleus, the potential well “radius” is $R = R_0 A^{1/3}$, where R_0 , radius constant, is 1.4×10^{-15} m and A is the atomic number. The probability is $P = \exp\left[-(4\pi Z_D e^2 / \hbar v) + (8/\hbar)\sqrt{(Z_D e^2 M_0 R)}\right]$, with eZ_D the NUCLEAR CHARGE, e the electron charge, and $\hbar$ (h-bar) Plank’s constant divided by 2π and the REDUCED MASS of the alpha particle (accounted for due to the nuclear recoil): $M_0 = (M_\alpha M_D)/(M_\alpha + M_D)$, where M_α is the alpha particle mass and M_D the mass of the nucleus (see Figure A.60).

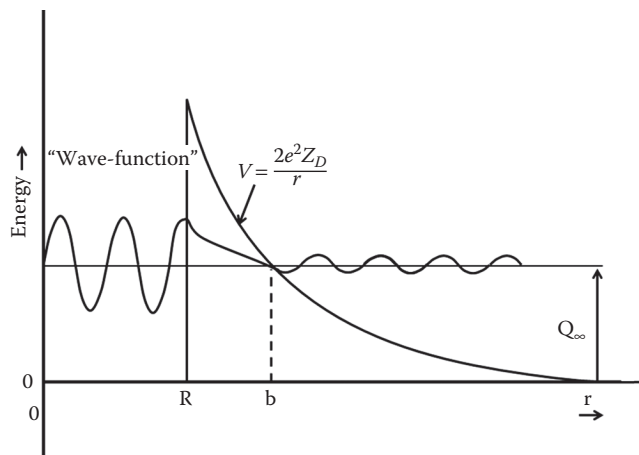


Figure A.60 Energy plot representing the potential well for alpha decay for an atomic nucleus.

Alpha decay energy

[atomic, general, nuclear, quantum, solid-state] ($Q: {}^A_Z P \rightarrow {}^{A-4}_{Z-2} O + {}^4_2 \text{He} + Q$, with ${}^A_Z P$ the parent ATOM, ${}^4_2 \text{He}$ the ALPHA PARTICLE, and ${}^{A-4}_{Z-2} O$ the offspring and where the rest MASS ENERGY is $Q = (m_p - m_o - m_\alpha)c^2$; this goes primarily to the kinetic energy of the alpha particle, with residual energy in nuclear recoil. Sometimes, two alpha particle are emitted in the RADIOACTIVE DECAY process, however, with different respective energies. The difference in energy is covered in CONSERVATION OF ENERGY by emission of a GAMMA RAY with the remaining energy. This process is seen in the radium decay process to the unstable radon ISOTOPE (radon NUCLEUS) with $E_\alpha^1 = 4.78$ MeV and $E_\alpha^2 = 4.59$ MeV next to 0.19 MeV gamma ray emission.

Alpha particle

[atomic, biomedical, nuclear, quantum, solid-state] α PARTICLE with the following constituents: two protons and two neutrons, equivalent to a helium NUCLEUS, with associated double POSITIVE CHARGE. The mass is 4.002764 amu (atomic mass units). The alpha particle has little kinetic energy and will be stopped by a sheet of paper compared to several CENTIMETERS of aluminum for γ -rays. The alpha particle can be detected by

means of a SCINTILLATION COUNTER (e.g., GEIGER COUNTER), a BUBBLE CHAMBER (CLOUD CHAMBER) or specialized SOLID-STATE devices (e.g., crystal or plastic, with embedded phosphor or anthracene that fluoresces).

A

Alternating current (AC)

[general] A FLOW of electrons periodically changing to reverse direction. (*Note:* The current direction is in the opposite direction of the flow of electrons).

al-Zarqali (Abū Ishāq Ibrāhīm ibn Yaḥyā al-Naqqāsh al-Zarqālī) (1029–1087)

[general] Scientist from Spain, also “Arzachel.” He is the first to document the statement before JOHANNES KEPLER (1571–1630) that PLANETARY ORBITS may be elliptical. Al-Zarqali an instrument maker, astronomer, and philosopher from what we now consider to be Spain, then momentarily under Arab–Islam rule, made his statement on the “oval” orbit of Mercury in 1081. He also made several other corrections to the established Ptolemaic model (see [Figure A.61](#)).



Figure A.61 Postage stamp with graphical interpretation of the likeness of al-Zarqali (1029–1087) from Spain.

AM radio

[general] AMPLITUDE modulated transmission of electromagnetic waves used for wireless SIGNAL transmission. The mechanism of operation is distinctly different from FM radio. The RADIO signal is generated by an alternating DIPOLE in oscillatory fashion over the length of an ANTENNA generating a CARRIER WAVE with a fixed frequency, which is modulated in amplitude by the superimposed signal WAVE. The accompanying alternating electric and MAGNETIC FIELD is described for the dipole (see DIPOLE, ALTERNATING). The superposition principle applies to electromagnetic waves. The broadcast frequency range is split in the following wavelength bands. The carrier wave is denoted by three denominations. The first transmission designation is long wave radio: 148.5–283.5 kHz. Long-wave (LW-) radio generally uses 9 kHz channel spacing. Next is medium-wave (MW-) radio: 520–1,710 kHz. Channel spacing varies between 9 and 10 kHz. Medium-wave radio is associated with the generally available information channels and music for commercial use. The last band is short wave broadcasting in the 1.711–30.0 MHz range. Short-wave (SW-) radio is subdivided into 15 bands; channels are generally separated by 5 kHz (see [Figure A.62](#)).



Figure A.62 An old-fashioned AM radio.

Amagat, Emile Hilare (1841–1915)

[thermodynamics] A scientist and physicist from France who had experimentally validated the superposition of the IDEAL GAS LAW for a mixture of gases.

Amagat's law of additive volumes

[thermodynamics] The assembly of the volumes of a number r gasses combined under same pressure P and temperature T of the amounts n_i representing the individual constituents yields an IDEAL GAS MIXTURE volume under equivalent conditions, that is, the sum of the constituents:

$$V(T, P, n) = \sum_{i=1}^r n_i (RT/P) = \sum_{i=1}^r n_i v_{ii}(T, P).$$

Amber

[general] Fossilized pine tree resin that is electrically charged when rubbed with fur or cloth. The first recorded observation of this ELECTRIC CHARGE phenomenon was by the Greek scientist THALES OF MILETUS (c. 624–546 BC) in around 590 BC. Later, PLATO (c. 427–347 BC) also described the effects of Amber as having attractive powers. The Greek name for amber is “Electron” (ἤλεκτρον), establishing the initial nomenclature for modern electrical ENGINEERING.

Amorphous media

[general] Solids that behave in a fashion primarily know to liquids. GLASS is in an amorphous state, technically a LIQUID but with fixed and rigid shape. Other familiar concepts include shaving cream, certain make-ups, chocolate mousse, and butter. Additionally, volcanic magma could be considered in this group.

Ampère, André Marie (1775–1836)

[electromagnetism, general] A French mathematician and physicist during the time of Napoleon Bonaparte (1769–1821). He developed mathematical relationships between the MAGNETIC FIELD and electric current, recognizing certain innate characteristics of current before the development of the atomic model by NIELS BOHR (1885–1962). The unit for current was named after him. His mathematical verve laid the foundation for many electromagnetic and electrodynamic laws. Ampère's work was taken on by the Danish scientist HANS CHRISTIAN ØRSTED (1777–1851) resulting in several significant experimental validations of Ampère's theories. Their combined work led to the discovery of a link between MAGNETISM and ELECTRICITY

in 1819. His mathematical contributions were in the recognition of the values imbedded in the second-order derivative in partial differential equations (see [Figure A.63](#)).



Figure A.63 André Marie Ampère (1775–1836).

Ampère

[biomedical, electronics] The **MAGNITUDE** of a current in two wires that are lined up parallel to each other at separation **DISTANCE** $r = 1\text{ m}$ that produces a **MAGNETIC FORCE** (F_B) per unit length (ℓ) between the two wires of $2 \times 10^{-7} \text{ Nm}^{-1}$, based on the Lorentz force: $F_B/\ell = \mu_o^{\text{magn}} I_1 I_2 / 2\pi r$, where I_i is the respective electrical current in either wires and μ_o^{magn} the permeability of the medium the wire is suspended in. The force is the direct result of the **MAGNETIC FIELD** (**B**) generated by the current in each wire as $\mathbf{B} = \mu_o^{\text{magn}} I_1 / 2\pi r$. The ampère is also equivalent to the **FLOW** of charge of $1\text{ A} = 1\text{ C/s}$, one coulomb per **SECOND**.

Ampère (A)

[biomedical, general] Unit of electric current expressed as charge per unit time [C/s], also 3×10^{19} electrons/s. It has been originally defined as the amount of current that will deposit 1.118 milligram of silver per **SECOND** on the **CATHODE** of a **CONDUCTOR** placed in a silver **SOLUTION** along with the **ANODE**. It is often described as measured by an ammeter.

Ampère's law

[general] Electrical equivalence described by **MARIE AMPÈRE** (1775–1846) between the current through a **CONDUCTOR** and the **MAGNETIC FIELD** produced by this current. Because magnetic field lines form a closed loop, the summation of the magnetic field along individual segments of an arbitrary loop that encloses one or more current carrying conductors with respective currents is directly proportional to the sum of the enclosed currents. Only the components of the magnetic field tangential to the loop are added for the loop, expressed as $\sum \bar{B}_{\parallel} \Delta \ell = \mu_0 \sum I$, or in integral form: $\oint \bar{B} \cdot d\ell = \mu_0 I$ or $\oint \bar{H} \cdot d\ell = I$ for any arbitrary closed loop, where $\bar{B}$ is the magnetic field strength, $\bar{H}$ is the magnetic **FLUX** density, which has a **HYSTERESIS** with respect to the magnetic flux as described by **JAMES CLERK MAXWELL** (1831–1879), ℓ the path of the loop of integration around the current I , and μ_0 the **DIELECTRIC** permittivity. An alternative way to define Ampère's law is as follows: $\nabla \times \bar{H} = \mathbf{j}$, where $\mathbf{j}$ is the current density. An equivalent mathematical description was derived by **PIERRE-SIMON DE LAPLACE** (1749–1827) based on work by **JEAN-BAPTISTE BIOT** (1774–1862) and **FÉLIX SAVART** (1791–1841). James Maxwell later introduced a revision incorporating the **FLOW** of charges (i.e., the electric flux: $\phi_e = EA = q/\epsilon_0$, with E the electric field, A the area, q the **ELECTRIC CHARGE**, and ϵ_0 the dielectric permeability) as displacement current ($\epsilon_0 (d\phi_e/dt)$) defined by $\oint \bar{B} \cdot d\ell = \mu_0 I + \mu_0 \epsilon_0 (d\phi_e/dt)$.

Amplification (M_A)

[electronics, general, optics] The process of increasing the AMPLITUDE of a SIGNAL, field-strength or MOTION by means of a mechanism that requires the supply of external ENERGY. Generally amplification is expressed in DECIBEL (dB). Electronic amplification of an electrical signal increases the voltage amplitude and hence the current from input to output with the use of an operational amplifier. Alternatively the use of current amplifiers is also practiced, as are transconductance amplifiers; supplying an output current proportional to the input voltage. Respectively, transresistance amplifier which generates an output voltage that is proportionate to the input current. Typically, filters are added to reduce the impact of NOISE in the amplification process. Filters are only beneficial when the signal frequency spectrum is reasonably well defined, hence rejecting portions of the FREQUENCY SPECTRUM that is considered to supply noise. Mechanical amplification can be obtained by means of a resonant cavity (e.g., casing of a string instrument), or continuous excitation at the resonant frequency (e.g., TACOMA NARROWS BRIDGE, Puget Sound–Washington, got destroyed because of the wind blowing on the suspension cables, forcing the cables in VIBRATION that matched the resonant frequency of the concrete and METAL main structure of the bridge; construction of the bridge started in 1938, opened in July 1940, and the bridge was destroyed in November 1940). The amplification of electric or magnetic fields can be achieved through induction under Faraday's law and LENZ'S LAW.

Amplifier, electronic

[general] See OPERATIONAL AMPLIFIER (OpAmp).

Amplitude

[general] The maximum value of the displacement in a mechanical oscillatory MOTION, or the MAGNITUDE of the maximum field strength of an oscillating electric or MAGNETIC FIELD.

Amplitude modulation (AM)

[general] Superposition of two waves: a CARRIER WAVE and a modulating SIGNAL wave. The information stored in the AMPLITUDE is retrieved by tuning to one specific carrier wavelength and deconvolving or demodulating the superimposed information stream by a tuning circuit composed of capacitors, resistors, and inductors (potentially imbedded in solid-state ELECTRONICS; see INTEGRATED CIRCUIT). The signal can be electromagnetic (e.g., see AM RADIO, TELEVISION) or mechanical (e.g., ULTRASOUND) (see Figure A.64).

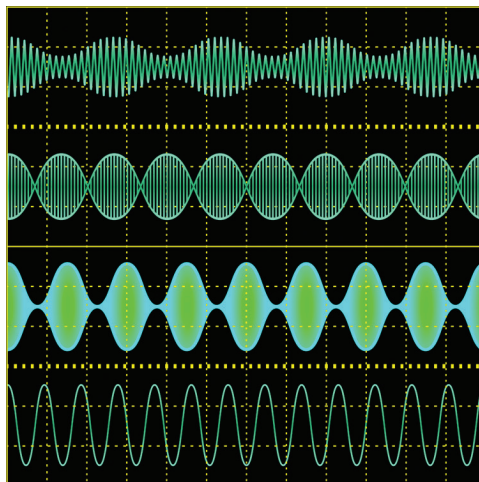


Figure A.64 Signal pattern with imbedded amplitude modulation.

Anaerobic respiration

[biomedical] Cellular METABOLISM operating without OXYGEN. The process changes the chemical structure of CARBOHYDRATES to generate ATP; however no REDUCTION takes place with a relatively low conversion efficiency in comparison to AEROBIC respiration. The short-term ENERGY that is stored is rapidly depleted causing LACTIC ACID concentrations to accumulate to the point where MECHANICAL EFFORT by the MUSCLE becomes impossible. The point at which the muscle becomes subject to this lactic poisoning is referred to as the “anaerobic threshold.”

Analysis of the motion of a fluid element

[fluid dynamics] Using STOKES ANALYSIS, the respective components (x, y, z) in a three-dimensional space can be presented as having three orthogonally directed VELOCITIES (u, v, w) .

Anatomy

[biomedical, general] A study of the construction and composition of biological entities. This science is mainly static; it does not concern itself with the way body part move. The study of the biological structure started with the first official documented proof in 1543 from ANDREAS VESALIUS (1515–1564): *Humani Corporis Fabrica*. Additionally, LEONARDO DA VINCI (1452–1519) contributed to this new line of thought with extensive drawings and theoretical analysis (see [Figure A.65](#)).

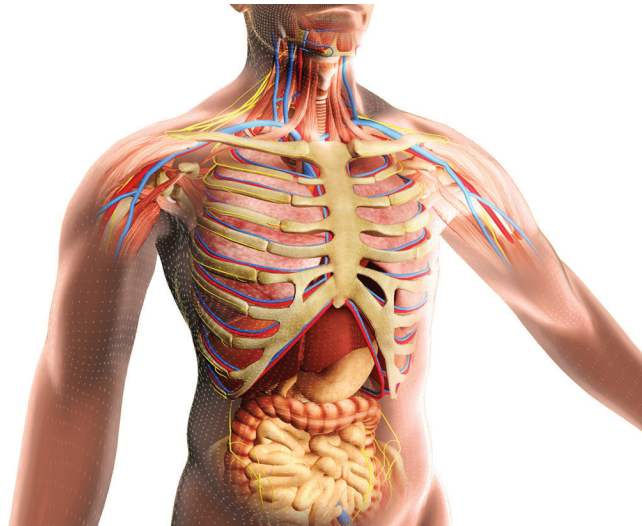


Figure A.65 Example representation of human anatomy.

Anderson, Carl David (1905–1991)

[atomic, energy, general, nuclear] An American physicist who is known for the discovery of several ELEMENTARY PARTICLES such as the POSITRON in 1932 and the MUON in 1938. He started out under ROBERT A. MILLIKAN (1868–1953) in CLOUD-CHAMBER analysis for COSMIC RAYS. His positron discovery was a direct

validation of the theoretical description of this phenomenon by PAUL ADRIEN MAURICE DIRAC (1902–1984) (see [Figure A.66](#)).



Figure A.66 Carl David Anderson (1905–1991) from the Nobel Prize files.

Andromeda Galaxy

[astronomy, astrophysics, general] It has a spiral configuration. Andromeda is part of the Andromeda CONSTELLATION, with a name derived from Greek mythology, namely the daughter of CASSIOPEIA. It is located directly beneath the Cassiopeia constellation in the northern sky, visually in the direction of the NORTH POLE. The GALAXY is cataloged as both M31 and NGC 224 in the Messier astronomical catalog (denoted by the letter M), as defined by Charles Messier in 1764, and the “New General Catalogue” (NGC), respectively. The NGC was introduced by JOHN LOUIS EMIL DREYER (1852–1926) in 1888. Andromeda is the closest galaxy with respect to our MILKY WAY (see [Figure A.67](#)).



Figure A.67 Reconstructed image forming an impression of how Andromeda is outlined from our point of view.

Anechoic

[acoustics, electromagnetism, imaging] Structure designed to eliminate and/or prevent reflections (see [Figure A.68](#)).

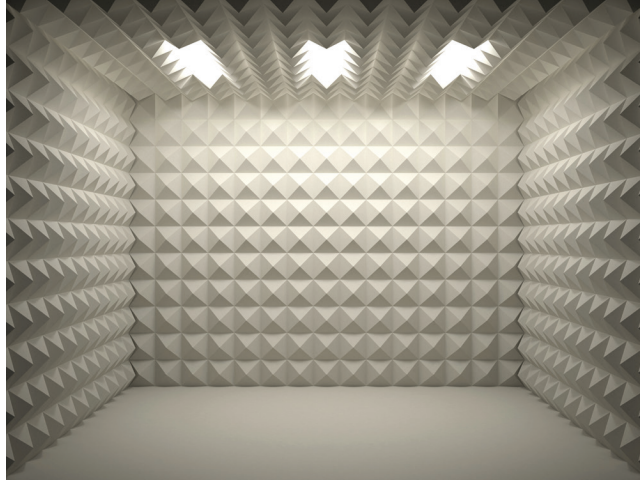


Figure A.68 An anechoic chamber.

Anelasticity

[mechanics, solid-state] A time-dependent variant of HOOK'S LAW OF ELASTICITY for the relationship between STRAIN (ϵ) and STRESS (σ): $\epsilon = J\sigma$. An anelastic solid will display a lag between FORCE (F) and stress, while the relationship between stress and strain is preserved permitted there is an allotment for time to allow the Hook's equilibrium to be reached. Stress and strain will following the behavior described as $J_R\sigma + \tau J_u(d\sigma/dt) = \epsilon + \tau(d\epsilon/dt)$, which solves for a constant stress as displaying what is known as "CREEP." The equation defines the following concepts: J_u is the unrelaxed COMPLIANCE that describes the response to an instantaneous force: $J_u = [\epsilon(0)/\sigma_0]_{t=0}$, $J_R = \lim_{t \rightarrow \infty} (\epsilon/\sigma_0)$ is the relaxed compliance, and τ is the RELAXATION TIME of the transformation under a force applied over a time t at constant stress (see [Figure A.69](#)).

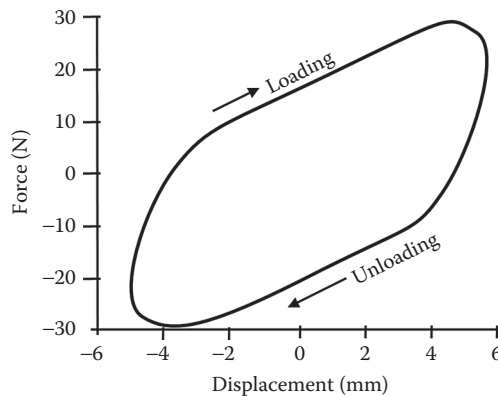


Figure A.69 Hypothetical mechanical behavior for an anelastic medium under applied force.

Anemometer

[fluid dynamics] A device for measuring wind VELOCITY (v) and airflow. The first wind anemometer was invented by Leon Battista Alberti (1404–1472) in 1450. Several mechanisms are available that can provide FLUID velocity based on interaction of AIR flow with a sensing mechanism. The cup anemometer rotates under the applied force by the wind and the angular velocity directly correlates to the wind velocity taking the arm length with respect to the cup catching the wind into account. The hot-wire anemometer has a glow wire that will have a HEAT TRANSFER with its direct environment proportional to the wind velocity. Optical device used for FLOW measurement use either light SCATTERING by particles in the fluid (air, LIQUID) or variations in density expressed as variations in refractive index. Examples of optical anemometers include interference-fringe anemometer and laser-Doppler anemometer. The interference-fringe method depends on the refractive index gradients resulting from flow velocity gradients and a split laser beam that is converged and recombined after passing through a stream creating INTERFERENCE patterns on transmission similar to Moiré interferometry, whereas the DOPPLER technique measures the velocity from particles based on frequency shift. The fringe INTERFEROMETER detects a “beat” frequency (v_d) that is proportional to the local velocity perpendicular to the intersection plane of the two laser beams with wavelength λ_0 at a relative ANGLE with each other (θ) expressed by $v_d = (2v/\lambda_0) \sin(\theta/2)$. The sonic or acoustic anemometer is based on the speed of SOUND combined with the velocity of the air-flow to provide a time-delayed detection of the sound source. Pitot tubes (also called “Prandtl tubes”), on the other hand, are used to determine fluid flow velocity by determining the difference between the static pressure (P_s) and dynamic pressure ($P_d = (1/2)\rho v^2$) in the flow pattern of fluids. The Pitot tubes rely on the Bernoulli equation as $P_{\text{tot}} = P_s + (1/2)\rho v^2$, where P_{tot} is the total pressure and ρ the local fluid density (in this case assuming an INCOMPRESSIBLE FLUID). The Pitot mechanism is a variety of the VENTURE EFFECT. The anemometer is a crucial tool in determining surface layer effects in the lower atmospheric BOUNDARY LAYER. Specifically, the recognition of TURBULENCE is caused by relief patterns as well as the confluence of airstreams. One of the newer mechanisms used to measure airflow is by means of ULTRASOUND, for example, A-Probe ring anemometer from ATI. Other alternatives use a wire heated by electrical current, which will lose heat due to convection (see [Figure A.70](#)).

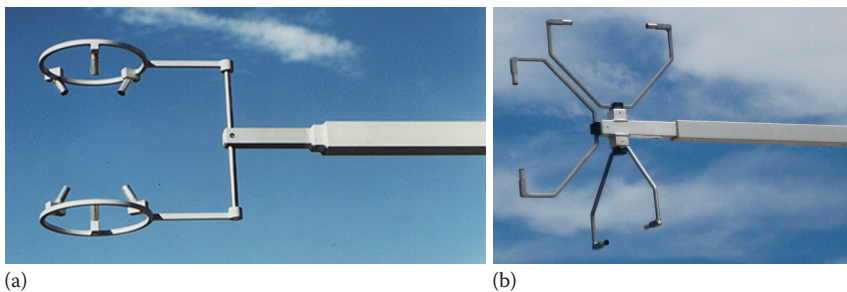


Figure A.70 Example of an anemometer used to measure wind velocity and direction. (a) One of a series of five ultrasonic (nonmechanical and can be used under virtually any weather conditions) anemometers from Applied Technologies, Inc., Longmont, CO. According to 2014 calibration tests, this series of anemometers has been verified as one of the most accurate ultrasonic anemometers available for scientific research. (b) Different ultrasonic anemometer design from Applied Technologies, Inc.

Aneurysm

[biomedical, fluid dynamics] Localized widening of an artery, usually combined with a thinning of the vessel WALL. The incident is attributed to both intra-arterial pressure and FLOW phenomena. Generally, the segment of a vessel that is involved in the development of an aneurysm has TURBULENCE or low-flow due to

the vessel geometry and infrastructure. Aneurysms often develop in curved vessel segments or near bifurcations. The arterial flow creates shear stress on the surface of the inner lining of the wall, which induces change in the chemical interaction between specific BLOOD components and the lining of the vessel wall. In addition, the flow associated with the vascular geometry has a complex turbulent structure that induces a frictional BOUNDARY LAYER, which applies a tangential force on the material structure. As a result of all the physical characteristics, both material and chemical changes are initiated, which in turn worsen the initial flow conditions. An aneurysm has a weakened integrity of the vascular wall, which may rupture under certain conditions, specifically under increased local pressure. Aneurysms in the brain and in the AORTA frequently have lethal consequences. Because of the turbulent conditions in the aneurysm, the blood itself is also affected, potentially leading to thrombus formation (blood clot) as well as the formation of EMBOLISM (BUBBLE formation, sealing of the vessel for flow; fat globule) (see [Figure A.71](#)).

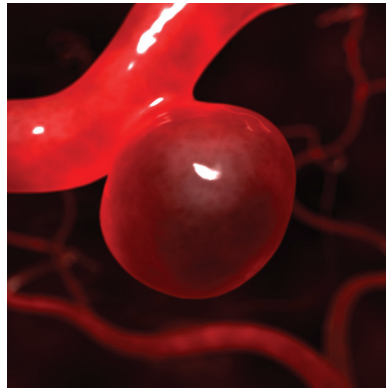


Figure A.71 Representation of a vascular aneurysm. These types of thin-walled vessel protrusions can burst, resulting in massive blood loss and, depending on location, instantaneous death.

Angle

[general] For example θ and α , the geometric span of an arc (i.e., curved length of line with constant curvature) between two lines, planes, or spaces that intersect in one point or shapes that do not intersect but have respective axes that when extended intersect. The ANGLE can be measured/defined between two points on a surface with no constant curvature such as the contour of a WING of an airplane as measured between two points that are separated close enough that by first- or second-order approximation the DISTANCE to a center-point of curvature (i.e., origin) can be considered identical. Also, the use of tangents to respective surfaces can be defined by an angle at the point of extended intersect. *Note:* The straight line connecting the two ends of an arc is called a “chord.” Angles can be in two or three dimensions, three-dimensional angles are called “SOLID ANGLE.” Angles are defined in either degrees ($^{\circ}$) and radian (rad), or in three-dimensional steradian, the circumference of a circle has 360 degrees (360°) or 2π radian [2π rad], whereas in three dimensions, the solid angle spans 4π steradian (4π sr). The radian is defined as the ratio of the length of the bow of an arc and its radius (length to arc from point of curvature).

Ångström, Anders Jonas (1841–1874)

[general] A Swedish astronomer and physicist who dedicated his work to the explanation of predominantly the solar spectral lines (see [Figure A.72](#)).

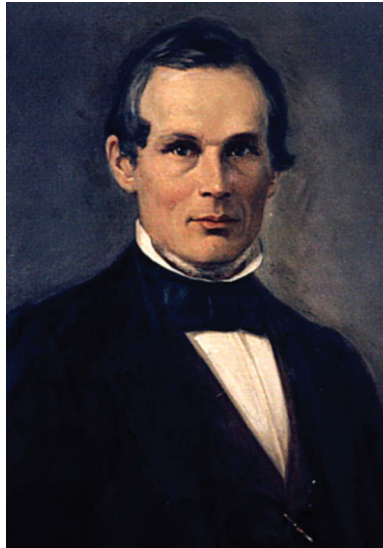


Figure A.72 Painting of Anders Jonas Ångström (1841–1874) by an unknown artist.

Ångström, Knut Johan (1857–1910)

[optics, thermodynamics] A Swedish physicist famous for his discoveries in the INFRARED part of light. He is the son of Anders Jonas Ångström.

Ångstrom unit

[atomic, nuclear] A measure of size named after ANDERS JONAS ÅNGSTRÖM (1841–1874), $10^{-10} \text{ m} = 10^{-1} \text{ nm}$.

Angular acceleration (α)

[biomedical, general, mechanics] The rate of change in ANGULAR VELOCITY ($\omega(t)$) with respect to a reference frame or fixed point for an object moving in curved trajectory, or the rate of change in direction of axis of rotation. The definition of angular velocity is $\alpha = d\omega/dt$ (rad/s^2).

Angular displacement (θ)

[biomedical, general, mechanics] In rotational KINEMATICS, the ANGLE of the curved circular path of a moving point on an object revolving around a central axis measured with respect to the axis of rotation in reference between two points in time. The angular displacement relates to the arc of the circular trajectory (s) as a function of DISTANCE (r) to the axis of rotation as $s = r\theta$.

Angular frequency (ω)

[general] Rotational velocity of an object revolving around its own axis or an object in orbit around a FOCAL POINT, generally consisting of an object with attractive force (electrical or gravitational). Additionally, the angular frequency of a periodic event is associated with the sinusoidal periodicity, which can also be plotted as a circular phenomenon with changing AMPLITUDE as a function of ANGLE (α) as a function of time (t): $\omega = \partial\alpha/\partial t$.

Angular impulse

[biomedical, general, mechanics, quantum] Change in angular momentum. A gymnast performing a (dual, triple) somersault can change the angular momentum when touching the GROUND/balance-beam, or touching the second bar on the uneven bar exercise (*also see* ANGULAR INERTIA) (see [Figure A.73](#)).

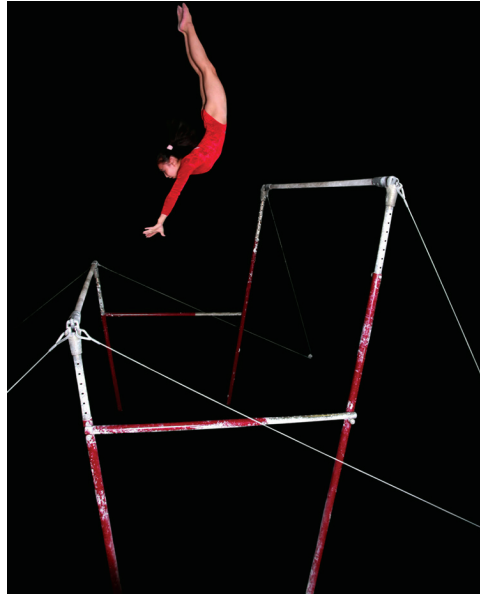


Figure A.73 A gymnast who changes angular impulse when touching an object in their path.

Angular inertia ($I\alpha$)

[biomedical, general, mechanics, quantum] Moment of INERTIA of a rotating body multiplied by the angular acceleration. The angular inertia is directly correlated to the TORQUE (τ) applied to the revolving object (revolving around its own axis or around another object while in orbit): $\tau = I\alpha$. One particular example is found in an avalanche or rock-slide (see [Figure A.74](#)).



Figure A.74 The angular inertia of a rolling object, seemingly unstoppable, as experienced during an avalanche.

Angular magnification (M_α)

[general, optics] The ratio of the ANGLE of the incoming beam (acceptance angle) as observed with a LENS (aided: α_{aid}) to the angle of observation received without a lens (unaided: α_{un}): $M_\alpha = \alpha_{\text{aid}}/\alpha_{\text{un}}$ (see Figure A.75).

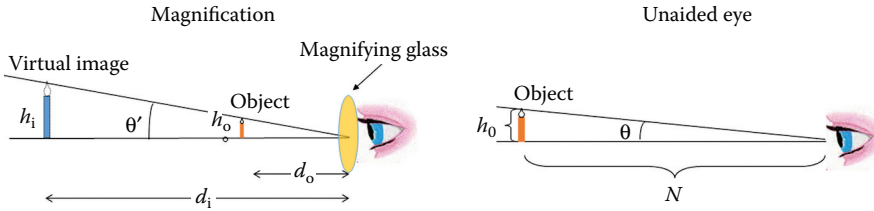


Figure A.75 Angular magnification under the influence of a lens in the path of vision, specifically pertaining to the use of eye glasses (spectacles).

Angular momentum (L)

[biomedical, general, mechanics, quantum] Representation of the propensity of a rotating body to remain in rotation at constant angular velocity around the axis of symmetry, or the axis of rotation, similarly described by the NEWTON'S FIRST LAW OF MOTION OR LAW OF INERTIA. There is both a classical and a QUANTUM mechanical interpretation. The classical angular momentum references the momentum (p) of a moving object(s) with mass m (respectively: center of mass) taking in the perpendicular direction to a line connecting with the origin of a reference frame (at a DISTANCE, r), or equivalently a fixed point in space as the axis of rotation. This is expressed as $L = r_\perp m \odot v = r \otimes p$. The fixed point can be the attachment of an arm/ LEVER, such as the elbow. Consider the rotational counterpart to linear momentum. When applied to a rotating unit of mass the angular momentum can be related to the moment of inertia (I) as $L = I\omega$, with $\omega = v_\parallel/r$ the angular velocity around the axis of rotation, and $v_\parallel$ the tangential velocity of the moving entity. *Note:* under this definition even a PARTICLE moving in a straight line can have an angular momentum. On a planetary level, Kepler's law is a direct consequence of the CONSERVATION OF ANGULAR MOMENTUM. On an atomic or elementary particle level, each atomic or subatomic constituent has a fundamental angular momentum, and this phenomenon is described in quantum mechanical terms. For instance, the revolution on its own axis for an electron the angular momentum is quantized and is named the "intrinsic SPIN," not to be confused with the "ORBITAL ANGULAR MOMENTUM" of the NUCLEON circling a nuclear grouping. The quantum-mechanical SPIN angular momentum of a nucleon is defined as $L = s\hbar$, where s is the spin quantum-number. Neutrons, electrons, and protons have an intrinsic spin of $(1/2)\hbar$. The TOTAL ANGULAR MOMENTUM for the combined respective contributions of the constituents obeys the superposition principle; this means that for even atomic number, however, that nucleon pairs need to be broken up, whereas odd-odd nuclei are not restricted in their excitation and joining mechanisms. The TOTAL NUCLEAR angular momentum for each constituent: $j\hbar$ is governed by the quantum-mechanical coupling rules, yielding the vector addition of the intrinsic spin and the orbital angular momentum: $\ell\hbar$, with ℓ the azimuthal—or orbital-quantum number and j the total QUANTUM NUMBER, which in this case is limited to the values: $j = \ell + (1/2)$ and $j = \ell - (1/2)$. The angular momentum is now given as: $L = \sqrt{v(v+1)}\hbar \approx v\hbar$ ($v = 0, (1/2), 1, 1(1/2), 2, 2(1/2), \dots$), indicating the limitation to the maximum value of the vector component in any direction. For even mass-number-A nuclei only the integers of v apply and for odd-A nuclei the values are $n + (1/2)$; n = integer. In this notation, $\hbar$ is the Plank's constant h divided by 2π ; $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$. This forms the basis for the theoretical description of the filling order in the Bohr model and the filling constraints of the ENERGY levels in the nuclear quantum well (i.e., maximum

occupation numbers). The net rate of change in angular momentum equals the torque on the moving compilation of mass or respective the sum of the torque on all moving masses. One final quantum-mechanical interpretation of angular momentum is the PRECESSION of a PROTON in an external MAGNETIC FIELD as experienced under nuclear MAGNETIC RESONANCE imaging (NMR/MRI). The precession of the angular momentum of the proton is initiated by the application of torque resulting from the interaction with an external MAGNETIC FIELD causing a change in angular momentum that is perpendicular to the existing angular momentum of the proton. The inherent magnetic moment (vector) will now gyrate in a cone-shaped revolution around the applied magnetic field. The rate of precession is called the “LARMOR FREQUENCY” (i.e., LARMOR PRECESSION) (see [Figure A.76](#)).

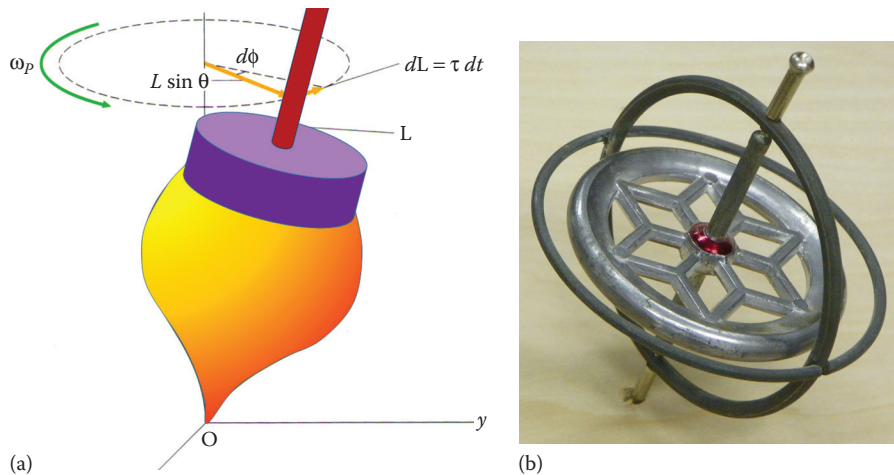


Figure A.76 (a) The angular momentum of objects performing a revolution. The best-known example is the spinning top (b); however, the same principles apply on microscopic level for electron spin as well as for galactic objects, including planets, black holes, and galaxies.

Angular momentum, conservation

[atomic, general, mechanics] When no external torque is applied to a system, the TOTAL ANGULAR MOMENTUM will be conserved because there is no change in internal ENERGY content. During RADIOACTIVE DECAY, the CONSERVATION OF ANGULAR MOMENTUM places restrictions on the PARITY change of the process as well as determining the “allowed” transitions and defining FERMI DECAY and GAMOW–TELLER DECAY constraints.

Angular quantum number (azimuthal)

[atomic, nuclear] QUANTUM NUMBER defining the angular momentum L for electrons in orbit (ℓ) as $= \hbar \sqrt{\ell(\ell+1)}$ ($\hbar$ is the Plank’s constant h divided by 2π ; $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$). It is also used in Azimuthal angular quantum number.

Angular speed (ω)

[general] The angular (θ) rate of change in a curved ($\sim$ circular) orbit: $\omega = d\theta/dt$ (see [Figure A.77](#)).



Figure A.77 The rate of angle change velocity for an object in continuously changing angle motion around one or more principal axis (an ellipse track has two principal axes).

Angular velocity (ω)

[general, mechanics, quantum] (rad/s) The rate of change in angular position with respect to a reference frame or fixed point for an object moving in curved trajectory; the definition of angular velocity is $\omega = d\theta/dt$. This angular velocity is constant for every point in uniform circular MOTION, since the rate of change in angular position is independent of the DISTANCE to the origin. The angular velocity also relates to the hypothetical circular orbit of the time-dependent sinusoidal AMPLITUDE of an alternating SIGNAL, which repeats every 2π radians or one period. Examples of waves with a sinusoidal pattern are ELECTRO-MAGNETIC RADIATION and SOUND. The tangential VELOCITY (v) of a point in circular motion will increase with distance (r) to the axis as: $v = r\omega$.

Anion

[biomedical, chemical, energy, electronics] PARTICLE (ION) with POSITIVE CHARGE, which is attracted by the ANODE.

Anisotropic oscillator

[computational, mechanics] Mechanical OSCILLATOR with more than one degree of freedom that has a different elastic modulus or direction specific elastic spring constant for various directions. Most three-dimensional system is anisotropic, including, but not limited to, a violin or a drum next to layered AIR masses with different temperatures. Another example would be a PENDULUM with the axis not perfectly in perpendicular orientation to the normal force. For electromagnetic oscillations this also applies to materials with BIREFRINGENCE, providing DISPERSION. In QUANTUM MECHANICS, this also applies to a system with mass m , solving for the SCHRÖDINGER EQUATION with the three-dimensional Hamiltonian: $H = -(\hbar^2/2m)\nabla^2 + (m/2)(\omega_1^2 x_1^2 + \omega_2^2 x_2^2 + \omega_3^2 x_3^2)$, with three-directional angular frequencies ω_i and $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ Planck's constant. In the isotropic case $\omega_1 = \omega_2 = \omega_3 = \omega$.

Annealing

[computational, engineering, solid-state] Two different meanings are associated with annealing, one for the solid-state ENGINEERING application and the other in computational science. In material properties, annealing references a heat treatment. The surface may be chemically altered to make it more resistant to scratches or thermally modified to make the material resilient to applied force in order to induce geometric modifications. Rapid heating and slow cooling will reduce the mechanical strength, whereas regular heating and fast cooling can increase the mechanical strength, as used to give hardness to the blade of a sword. In computational sciences, annealing of data refers to the process of reducing the SOLUTION domain in order to limit the complexity of a system, making it unsolvable. In QUANTUM MECHANICS, the quantum annealing technique provides the perturbation mechanism of action for combinatorial optimization of a GROUND STATE problem for systems with a crystal structure. The crystalline, or glassy DYNAMICS, refers to developing process at extreme slow incremental evolution, also referred to as “relaxation.” The relaxed state will have amorphous quantum states on MACROSCOPIC scale. In quantum mechanics, the quantum annealing provides the tools to solve for the time-dependent SCHRÖDINGER EQUATION in a real-time process within a range of constraints and approximations.

Annihilating pair

[atomic, biomedical, mechanics, quantum, solid-state] The combination of two complementary particles forming a new PARTICLE while losing their own identity. The joining of the two particles may also release ENERGY. This release can be in the form of ELECTROMAGNETIC ENERGY such as gamma RADIATION. One example of an annihilation pair is a positron–electron pair. A POSITRON (β^+) is a short-lived particle that has the same mass as an electron and is positively charged, and it has the same rest energy as an electron. Generally, the travel DISTANCE of a positron is limited due to the density of the free electrons in the volume surrounding the positron, primarily less than 1 millimeter, as described by the ANNIHILATION RATE. A free positron will virtually immediately annihilate with any of the many free electrons in the residing medium. This reaction is governed by CONSERVATION OF ENERGY. The energy of the electron before collision with a positron is marginally more than the rest energy. The momentum of the electron on impact can be taken as negligible. The positron–electron annihilation process releases a substantial amount of energy equivalent to the REST MASS of the initial particles, described by conservation of energy as: $m_{\text{pos}}c^2 + m_e c^2 - 2h\nu_\gamma = 0$, where ν_γ is the frequency of the emitted radiation (gamma: γ), and m_{pos} and m_e the mass of the positron and electron, respectively. The annihilation energy is liberated as two gamma QUANTA, each with energy of 511 keV, radiating perfectly perpendicular to each other.

Annihilation rate (Γ)

[atomic, biomedical, nuclear, quantum, solid-state] The inverse of the positron lifetime. The positron lifetime is correlated to the electron density, yielding for the annihilation rate (*also see* DIRAC RATE): $\Gamma = Z_{\text{eff}}\pi r_e^2 n_m$, with Z_{eff} the effective number of free electrons per ATOM/molecule, n_m the molecular, respectively, atomic number density, c the speed of light, and r_e the electron radius. The effective number of free electrons per atom/molecule: Z_{eff} will depend on the specific ISOTOPE. Additionally, the kinetic ENERGY of the emitted positron will equivalently impact the energy exchange, proportionally raising the energy of gamma pair due to CONSERVATION OF ENERGY constraints.

Annulus, rotating liquid

[fluid dynamics] In a QUASI-STEADY STATE, the VORTEX in AIR during a TORNADO (CYCLONE) or a swirl in a coffee cup or a whirlpool in the ocean can be approximated by a rotating annulus. Additionally, a LIQUID bearing could also be included; however, this will introduce internal FLOW and stresses. In the theoretical (and practical) approach, rotating fluids become rigid object parallel to the axis of rotation ($\hat{x}$ -axis). The case of the rotating annulus was treated initially by the French mathematician and scientist PIERRE-SIMON, MARQUIS DE LAPLACE (1749–1827) in his treatise for Saturn’s rings in 1787 as well as the mathematician

and scientist HENDRIK ANTOON LORENZ (1853–1928) from the Netherlands developed theoretical models on this principle. The symmetrically moving body (also grouping of liquid) revolves around an axis which can be chosen in the z -direction, with an equatorial dissecting plane of symmetry. Generalized, this will be treated as an elliptical path, having two foci. However, the deviation from circular is small (DISTANCE from physical center to either FOCAL POINT divided by the smallest distance from the center to the edge $\ll 1$). The MOTION will have potential ENERGY as a function of location $\Omega = \rho\pi(\alpha_0 x^2 + \gamma_0 \zeta^2) + \text{constant}$. The pressure as a function of location in the annulus is expressed as:

$$(P/\rho) = (1/2)\omega^2 (D + x)^2 - \Omega + \left[S / \sqrt{(D + x)^2 + \zeta^2} \right] + \text{constant}.$$

The regular round annulus (still under the assumption that deviation from circular is negligible) will have a moment of INERTIA associated with its revolution; for a flat (i.e., cylindrical) annulus all the mass will be equally distributed yielding: $I = M \left\{ \frac{R^2 + (R + \Delta R)^2}{2} \right\}$, where R is the inner radius of the circular annulus, with WALL thickness ΔR and mass M . While for a tubular annulus the mass is proportional to the “thickness” of the annulus as a function of radius to the center, giving:

$$I = 4\pi\rho\sqrt{[(8r + 39r^2R + 30rR^2 + 10R^3)/15]}$$

with r the radius of the tube itself in the loop configuration and presumably uniform density ρ (see Figure A.78).

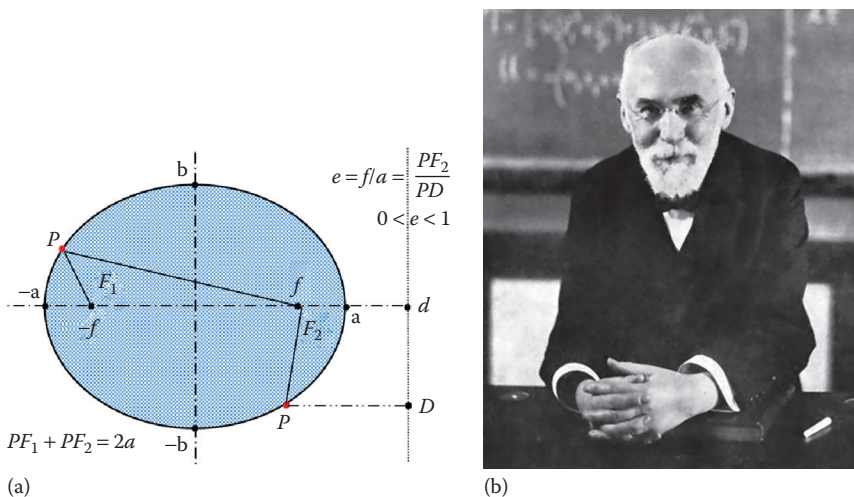


Figure A.78 (a) Geometric configuration of a rotating fluid annulus. (b) Hendrik Antoon Lorentz from the Netherlands. (Courtesy of the Boerhaave Museum, Leiden, the Netherlands.)

Anode

[biomedical, chemical, electromagnetism, general] Positively charged ELECTRODE, usually accompanied by the negatively charged CATHODE, as introduced by MICHAEL FARADAY (1791–1867). The word “anode” in Greek stands for the direction from which the SUN rises. Both a cathode and anode submerged in a SOLUTION of salt, ACID or base will divide the constituents of the respective electrolyte(s) to have the positive (CATION) and negative (ANION) charged ions to diffuse, respectively, to the cathode and anode.

Anomalous Zeeman effect

[atomic, general, nuclear] Random splitting of transition lines between electronic states under the influence of an external MAGNETIC FIELD. This phenomenon is a deviation from the theoretical explanation under the ZEEMAN EFFECT (see ZEEMAN EFFECT, ANOMALOUS). The counter phenomenon is the NORMAL ZEEMAN EFFECT.

Antagonist

[general, mechanics] Opposite in direction, mainly used for forces. ANATOMY: two muscles that operate the same joint but in opposing direction and with equal order of MAGNITUDE, one flexing the other under controlled relaxation (see Figure A.79).

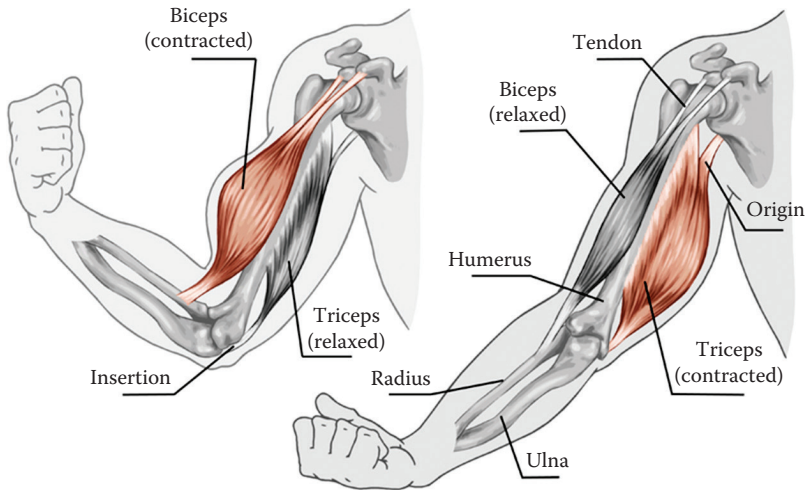


Figure A.79 Specifically in muscular action the torque on a joint cannot be reversed by the same muscle, requiring an antagonist to apply the force to return to the point of origin.

Antenna

[electromagnetism, general] System of conducting constructions that relay electric signals that are converted in the antenna to ELECTROMAGNETIC RADIATION to the outside (transmission) or collecting EM radiation for conversion to electrical signals (reception), for example, RADIO, television, and telephone. Various designations of antennas are used such as Hertz-A, Doublet-A, T-Antenna, and Parabolic (see Figure A.80).

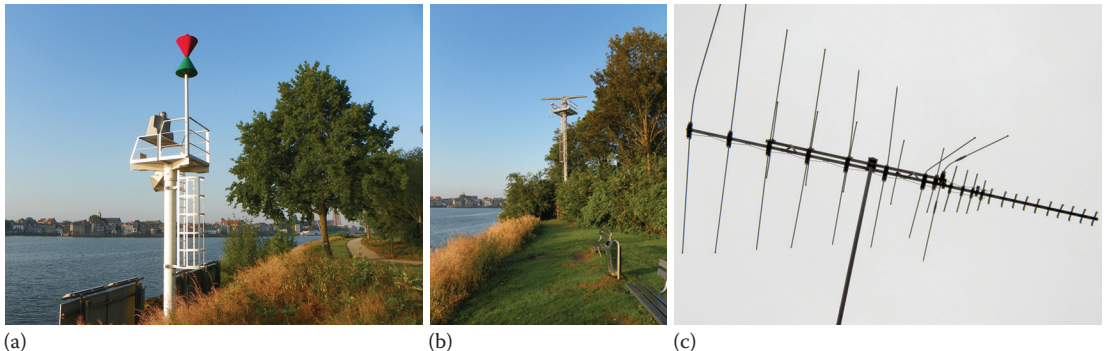


Figure A.80 (a–c) Variety of transmitting and receiving antennas operating over a broad electromagnetic band.

Antileptons

[general, high-energy, nuclear, quantum, solid-state] Counter particles of the family of leptons in the format of ANTIMATTER (*see* ANTIMATTER).

Antimatter

[atomic, general, high-energy, nuclear, quantum, solid-state] Phenomenon derived from QUANTUM mechanical theory in the form of: $E^2 = p^2c^2 + m^2c^4$. This equation has two roots, both positive and negative: $E = \pm c\sqrt{p^2 + m^2c^2}$. The negative roots would represent negative ENERGY, which is unattainable in classical terms, and even under quantum conditions this presented a problem. The negative terms are considered the physical embodiment of the dereliction from a genuine PARTICLE location and associated energy state (i.e., opposite state/particle), in inclusive mirror IMAGE from the real particle. Dirac's view on solid state has all the seemingly virtual counter states in the UNIVERSE occupied in inverted REFLECTION from the real quantum states. The antimatter particle on the other side of the looking GLASS has identical mass as its counterpart but negative energy and opposite charge. An example of an experimentally verified antimatter particle was the introduction of the positron to represent the "antielectron" concept. The creation and annihilation of antimatter obeys the CONSERVATION OF ENERGY principle, making it inherently more challenging to create an antiproton than making a positron based on the respective REST MASS energies. Some artificially produced antimatter particles are POSITRONIUM, antiprotonic hydrogen, antialpha, positron, ANTINEUTRON, antiproton, and concomitantly all subnuclear particles.

Antineutrino ($\bar{\nu}^*$)

[atomic, general, high-energy, nuclear, quantum, solid-state] Elementary PARTICLE with no CHARGE and negligible MASS compared to an electron emitted to preserve SPIN, momentum, and ENERGY primarily in nuclear DECAY as well as other processes (CONSERVATION OF SPIN, CONSERVATION OF MOMENTUM, CONSERVATION OF ENERGY, and CONSERVATION OF MASS). The antineutrino is produced in a similar process as the neutrino during the breakdown of a NEUTRON: $n \rightarrow p + e + \bar{\nu}^*$, where n is a neutron, p is a PROTON, and e an electron. ANTIMATTER particle counterpart of NEUTRINO (*see* NEUTRINO). The electron and anti-neutrino balance each other in such a way that when the electron ENERGY (i.e., KINETIC ENERGY) is high the antineutrino energy is low and vice versa. The antineutrino has an intrinsic ANGULAR MOMENTUM of $L = \hbar/2$, with $\hbar = h/2\pi$ the reduced PLANCK'S CONSTANT. The rotational direction of the antineutrino SPIN (clockwise/counter clockwise) is given by the LEFT-HAND RULE. The antineutrino is the counter part of the neutrino, which has a spin given by the RIGHT-HAND RULE, which is opposite from that of the antineutrino.

Antineutron

[atomic, general, high-energy, nuclear, quantum, solid-state] ANTIMATTER particle counterpart of NEUTRON (*see* NEUTRON).

Antinodes

[general] Crest and trough at maximum AMPLITUDE (both positive and negative) in WAVE pattern in contrast to the nodes which are always in EQUILIBRIUM STATE (amplitude zero), no deflection (*see* Figure A.81).

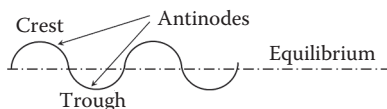


Figure A.81 Antinodes of a waveform: crest and trough.

Antipodal point

[computational] A point on a closed circumference that is diametrically opposed in location. Antipodal pairs are used on polygons to define the edges, while on a circle the points are dividing the circumference in two exact halves.

Antiproton ($\bar{p}$)

[atomic, general, high-energy, nuclear, quantum, solid-state] ANTIMATTER particle counterpart of PROTON (*see* PROTON).

Antiquarks ($\bar{q}$)

[atomic, general, high-energy, nuclear, quantum, solid-state] ANTIMATTER particle counterpart of elementary PARTICLE under the grouping quarks (*see* QUARKS).

Antireflection coating

[general] DIELECTRIC coating (e.g., PLASTICS) with a thickness that is a quarter WAVELENGTH ($d = \lambda/4$; quarter-wave plate) of the peak in the optical spectrum of interest. Antireflective coatings on EYE glasses are generally in the range where the eye is most sensitive: yellow-green. The coating design is configured to provide a REFLECTION coefficient between the coating and AIR to be equal to the reflection coefficient between the transparent medium (e.g., GLASS) and the coating. The coating and the medium will have a different index of REFRACTION n . The reflection coefficient for light polarized perpendicular to the PLANE OF INCIDENCE: $R_\sigma = (n_1 \cos \theta_i - n_2 \cos \theta_r) / (n_1 \cos \theta_i + n_2 \cos \theta_r)$ (ANGLE of incidence θ_i versus the refracted angle θ_r , SNELL'S LAW, theorem of Malus) is different from the light polarized parallel to the plane of incidence: $R_\pi = (n_1 \cos \theta_r - n_2 \cos \theta_i) / (n_1 \cos \theta_r + n_2 \cos \theta_i)$. The same principle can be applied in mechanical dampening by means of a mechanical transition. For instance, for two strings with mass per unit length m'_i the reflection coefficient at the joining point is $R = (\sqrt{m'_1} - \sqrt{m'_2}) / (\sqrt{m'_1} + \sqrt{m'_2})$ (*see* Figure A.82).

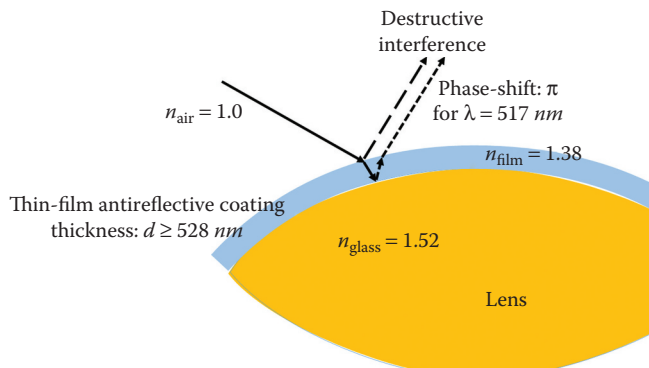


Figure A.82 Antireflective coating concept applied to corrective lenses in eye glasses.

Aorta

[biomedical, general] Compliant BLOOD vessel at the egress route of blood from the left ventricle behind the aortic VALVE. The AORTA has three sinuses that facilitate the outflow of blood from the HEART by means of allowing for TURBULENCE. The sinuses are outward bulges in the contour of the aortic WALL directly

downstream from the three respective leaflets of the aortic valve. The track of the aorta starts at the heart and arcs over to drop down into the abdominal cavity where it is named “abdominal aorta,” from where it splits in the lower abdomen/groin into the common iliac arteries. In the arc (approximately at a DISTANCE of 5–10 cm from the heart, respective to AGE, gender, and height) the aorta has two arteries leading off to the brain: the left- and right-subclavian arteries, respectively, further branching off into the carotid arteries (see Figure A.83).

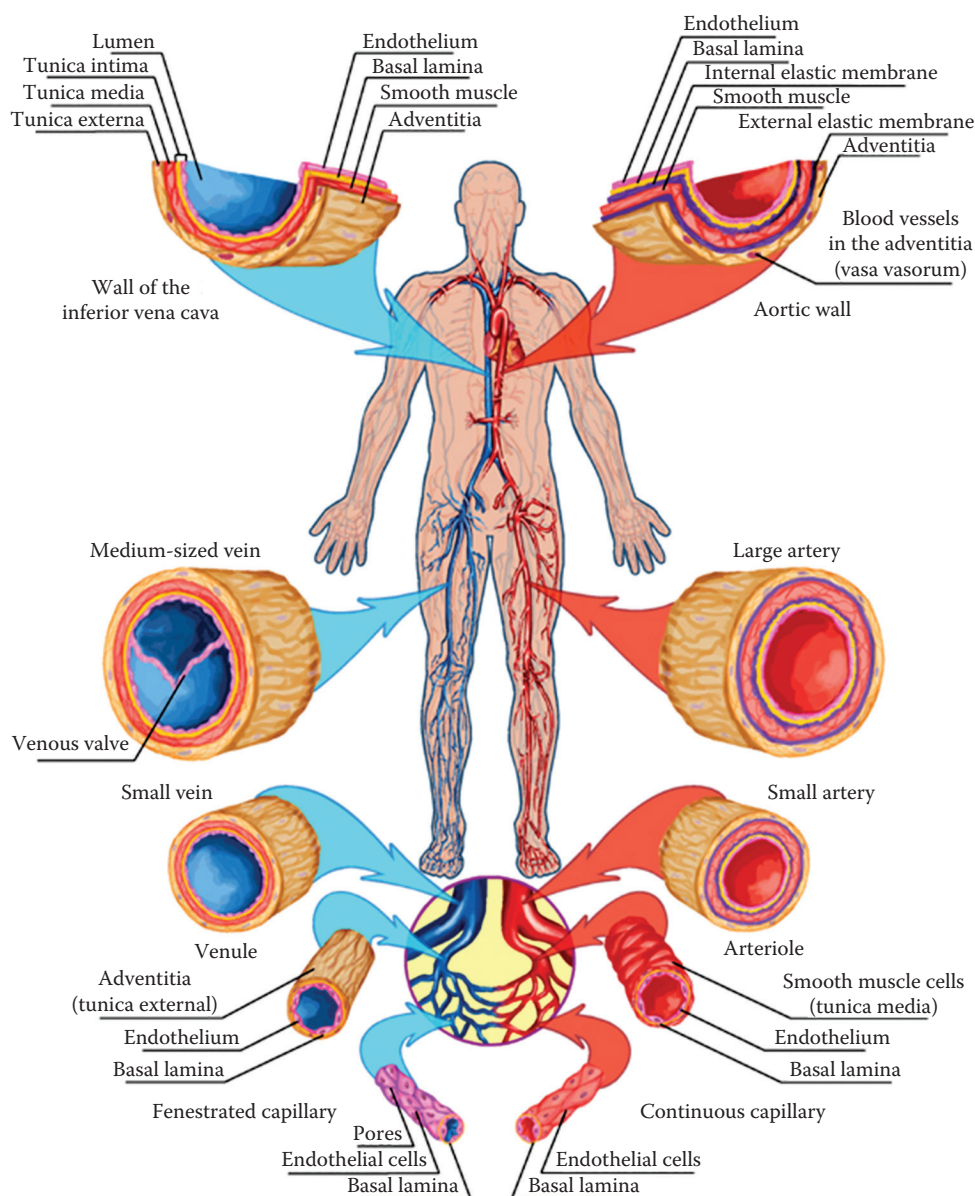


Figure A.83 Anatomical indication of the main artery, highlighted in red, emerging from the top of the heart at the left ventricle: the aorta. For humans, the aorta is several centimeters in diameter (depending on the size and stature of the person, as well as the athletic history and genetic predisposition). The aorta of a blue whale (a mammal—only several hundred remaining, on the verge of extinction) has a diameter in excess of 23 cm (attached to a heart, which is the size of a Volkswagen Beetle). The blue whale is the largest currently living mammal, with the length reaching up to 30 m.

Aperiphractic

[computational, fluid dynamics] Region in an irrotational segment of a moving FLUID, pertaining to Maxwell theory, that is defined by one or more closed boundaries. The closed spherical surface may be contracted down to a point without losing the confinement for the region.

Aperture

[acoustics, general, optics] Optical opening area, also referred to in PHOTOGRAPHY as “*f*-stop” (see [Figure A.84](#)).



Figure A.84 The aperture of a camera is used to set the light exposure and control the depth of field for a sharp image, primarily used in analog cameras, but can be found on advanced digital cameras as well; the aperture is an inverse indication, with 3.5 on this lens yielding the largest opening and 22 being the smallest opening. The aperture is the fraction of the focal length over the limiting diameter in the optical system, hence the aperture for a zoom-lens changes with the selected field of view. A large aperture will result in an extensive depth-of-field, whereas a small aperture number has a short depth of field, making only the object that is in focus sharp, blurring the background and foreground. The alternative term “*f*-stop” refers to the concept of focal ratio.

Apollo

[general] A rocket named for the Greek god “Apollo” in a long line of spacecrafts send out to investigate the UNIVERSE directly surrounding the EARTH, as well as and in particular the MOON, in addition looking out without atmospheric INTERFERENCE. The Apollo rocket system was constructed from three components, where the Earth launch tail-end (launch rocket) was discarded at elevation of approximately 68km. The Apollo program included 11 manned spaceships next to technically three unmanned Apollo missions in the period 1961–1972 as part of the U.S. President Dwight David Eisenhower (1890–1969) and U.S. President John Fitzgerald Kennedy’s (1917–1963) space program. The third human flight was with the Apollo 11,

aiming for an up-close and personal lunar observation. In 1969, the space ship Apollo 11 was the first craft to provide a manned landing on the Moon with the, after collecting the Lunar Module (moon shuttle and lunar rover) within orbit, manned by the astronauts from the United States: Neil Armstrong (1930–2012), and Edwin Eugene “Buzz” Aldrin (1930–), while Michael Collins (1930–) remained in orbit around the Moon with the remaining rocket. The use of a lunar-stationary rocket was at the time required to ensure the technical SOLUTION for a return to Earth. Later this issue was resolved with the Space-Shuttle program, a spaceship resembling a plane. Space-Shuttle program was initiated in 1969 with first flight in 1981 (see [Figure A.85](#)).



Figure A.85 A representative reconstruction of the Apollo moon landing shuttle, the Lunar Module.

Apparent mass

[general] See REDUCED MASS.

Apparent viscosity (η_{app})

[biomedical] Variability in VISCOSITY based on FLOW conditions, specifically CAPILLARY FLOW. This phenomenon is directly tied in with the FAHRAEUS–LINDQVIST EFFECT. The apparent viscosity is related to the standard KINEMATIC (also “DYNAMIC”) VISCOSITY (η_K) and the radius of the CAPILLARY tube (R) in which the flow takes place as well as the thickness of the cell-free layer (δ), which is of particular importance in colloid solutions such as BLOOD: $\eta_{\text{app}} = \eta_K \{1 - [1 - (\delta/R)]^4 [1 - (\eta_K/\eta_b)]\}$, where η_b is the viscosity of whole blood in the center of the flow.

Aqueous humor

[biomedical, optics] LIQUID transparent media filling the space between the cornea and the front of the CRYSTALLINE LENS of the HUMAN EYE. The liquid aqueous humor can morph to remain compliant with the changing curvature of the LENS during accommodation while maintaining a continuous transition between the optical media of the cornea and the lens to avoid distortions resulting from diffraction when air-bubbles

would be formed if the medium was more rigid. The aqueous humor has an index of REFRACTION of $n_{\text{aqueous humor}} = 1.337$, keeping in mind that water has $n_{\text{H}_2\text{O}} = 1.331$, and AIR $n_{\text{air}} = 1.0001$ (see [Figure A.86](#)).

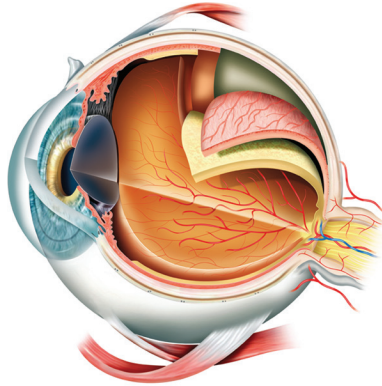


Figure A.86 Aqueous humor is the gel-fluid filling the main compartment of the eye, the volume between the lens and the retina. Increased pressure from excessive aqueous humor fluid will result in glaucoma, which can lead to blindness.

Arago, François Jean Dominique (1786–1853)

[general] A physicist, mathematician, and astronomer, as well as a politician from France. Working with AUGUSTIN-JEAN FRESNEL (1788–1827), he supported the WAVE theory of light in 1811. His theoretical work on the correlation between electrical current and voltage drew the attention of his fellow countryman ANDRÉ MARIE AMPÈRE (1775–1836) in the 1820s. Based on the wave theory, he also argued that the velocity of propagation must be a function of the medium and worked with ARMAND HIPPOLYTE LOUIS FIZEAU (1819–1896) and JEAN-BERNARD-LÉON FOUCAULT (1819–1868) to provide the proof for this in 1850. François Arago also effectively supported the development of the initial stages of PHOTOGRAPHY (DAGUERREOTYPE) by LOUIS-JACQUES-MANDÉ DAGUERRE (1787–1851). François Arago was also the twenty-fifth prime minister of France (see [Figure A.87](#)).

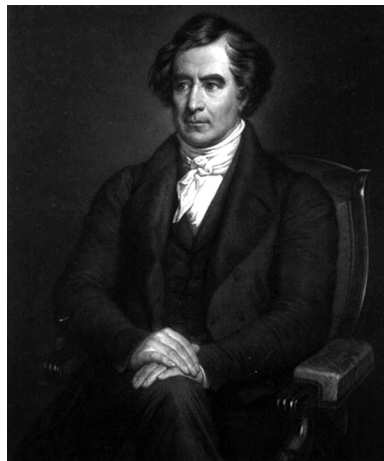


Figure A.87 Portrait of François Jean Dominique Arago (1786–1853), engraving by Alexandre Vincent Sixdeniers (1795–1846) from a painting by Henry Scheffer (1798–1862).

Arc discharge

[atomic, nuclear] In an ionizing medium (fluids, primarily gasses) the presence of a high ELECTRIC FIELD (E) can induce a displacement current. The IONIZATION materializes as an arc, with ENERGY released as photons. The formation of the arc is described by the empirical equation: $\sigma E^2 + (1/r)(d/dr)[rK(dT/dr)] - \epsilon' + a = 0$, where σ is the electrical conductivity, K the THERMAL CONDUCTIVITY, T the local temperature of the GAS with dissociated molecules, respectively, atoms and associate free electrons, r the DISTANCE from a pole with an applied electrical potential, ϵ' the volumetric EMISSION COEFFICIENT, and a the broad spectral volumetric absorption coefficient of the medium for all electric frequencies involved in the process (*also see* CORONA (-DISCHARGE), IONIZATION, LIGHTNING) (see [Figure A.88](#)).

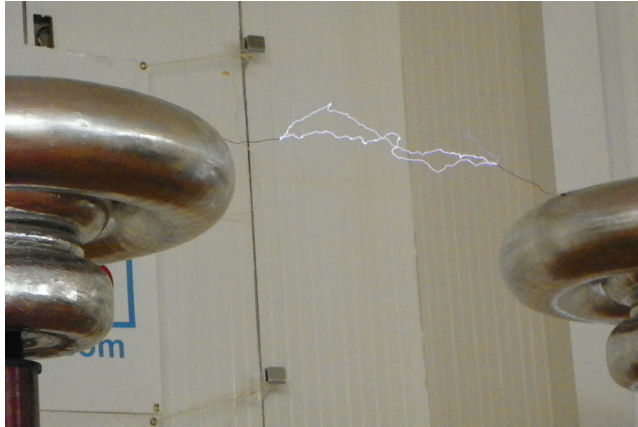


Figure A.88 Arc discharge in a Tesla coil configuration designed by Robert Beck.

Archibald approach to equilibrium method

[biomedical, chemical, mechanics] Mechanism of action used to determine MOLECULAR WEIGHT of the SOLUTE under ULTRACENTRIFUGE treatment. At the point of equilibrium between DIFFUSION and sedimentation the concentration $[C]$ will depend on the DISTANCE (r) to the axis of rotation as a function of ANGULAR VELOCITY ω . The molecular WEIGHT (M) distribution under ABSOLUTE TEMPERATURE (T) and rotational angular velocity: ω , with the assigned partial specific volume of the solute $\bar{V}$ expressed as $M(r) = RTr[C]/(1 - \rho\bar{V})\omega^2(d[C]/dr)$, where R is the UNIVERSAL GAS CONSTANT, and ρ is the SOLVENT density based on the dissolved constituent.

Archimedes

[biomedical, fluid dynamics, general] A mathematician and scientist (287–212 BC) from Syracuse then Greece, Sicily, now Italy. Most known for his formulation of BUOYANCY and additionally he developed a water corkscrew used for irrigation, and he presented the mathematical description of “regular bodies,” that is, Archimedes bodies. According to urban legend, Archimedes was taking a bath when he realized the

concept of buoyancy, that is, ARCHIMEDES' PRINCIPLE, and ran naked on the street calling out eureka ("I found it") (see [Figure A.89](#)).



Figure A.89 Artistic representation of a person known as Archimedes (287–212 BC) in the form of a statue.

Archimedes number ($Ar = g\rho L^3 / \eta^2$)

[astrophysics, fluid dynamics, geophysics, mechanics] The ratio of gravitational forces with respect to viscous forces, where g is the gravitational constant, ρ the density of the FLUID, L the characteristic length, and η the VISCOSITY.

Archimedes' principle

[fluid dynamics, general] A solid body in a LIQUID will experience an upward directed force that is equal but opposite to the WEIGHT of the displaced liquid, defined by ARCHIMEDES (287–212 BC) (see [Figure A.90](#)).

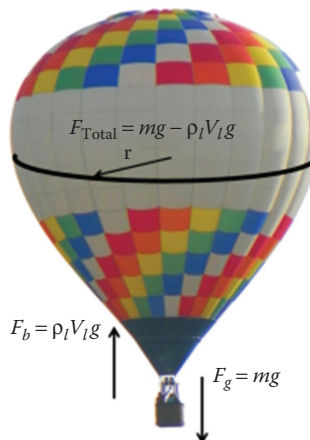


Figure A.90 Hot-air balloon levitation based on the Archimedes' principle.

Aristocles (427–347 BC)

[general] He is better known under the name Plato. A scientist and philosopher from Greece (*see* **PLATO** (427–347 BC)).

Aristotle (384–322 BC)

[biomedical, general] A Greek scientist from Stagira, Thracia, during the Macedonian era. He is a student and apprentice of **PLATO** (427–347 BC). Aristotle was the first to recognize that the **EYE** captured light reflected from an object, not that the eye emitted probing light itself. He postulated the concept of **AETHER**, the medium which allows light and **SOUND** to travel. He also wrote several transcripts on the biology, biological functioning, and reproduction of animals. On the mammalian experience, he posed the three states of existence: vegetative (nourish and reproduction), sensation (cognitive awareness and desire), and rationalism (decision making, only for higher mammals, i.e., humans). His work proposes that decisions are made based on emotions and are ruled by the **HEART**, not the brain as postulated by his preceding and contemporary scholars such as Plato and Democritus (460–370 BC). In addition to his scientific work, he was intrigued by politics and wrote a detailed description of the governmental structure and arrangements of the very differently organized 158 Greek states/countries (*see* [Figure A.91](#)).

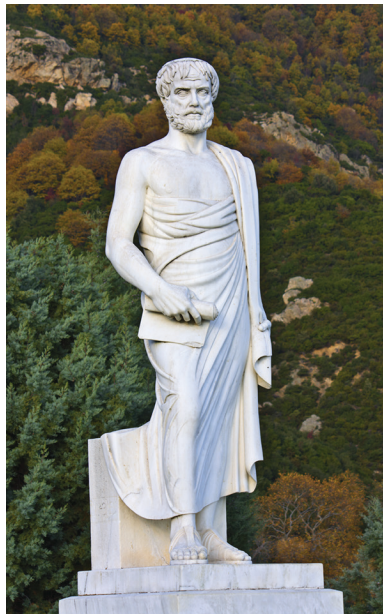


Figure A.91 Statue of Aristotle, artistic interpretation of period data and descriptive documentation by his contemporaries.

Aristyllus

[astrophysics, general] A fourth century BC, Greek scientist and astrophysicist. Together with **TIMOCHARIS**, they documented the first list of visible fixed stars.

Arndt–Schultz law

[biomedical, energy] Biostimulation. Physiological formulation of the biological stimulus of physiological **ACTIVITY** expressed as “weak stimuli excite physiological activity; moderately strong stimuli favor

physiological activity; strong ones retard physiological activity and very strong ones arrested physiological activity” (see [Figure A.92](#)).

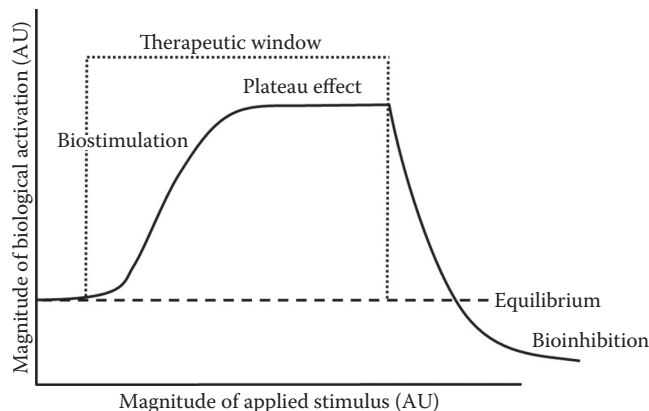


Figure A.92 The Arndt-Schultz law. In chemical reactions and biological activity, there will be an increase in chemical activity due to the administration of a stimulus (e.g., temperature and hormone) until a plateau is reached, while further increase of catalyst will result in decline and eventual inhibition.

Arrhenius, Svante August (1859–1927)

[atomic, computational, quantum] A Swedish chemist and professor of PHYSICS at the University of Stockholm. He worked with FRIEDRICH WILHELM OSTWALD (1853–1932), FRIEDRICH WILHELM KOHLRAUSCH (1840–1910), LUDWIG BOLTZMANN (1844–1906), and JACOBUS HENRICUS VAN’T HOFF (1852–1911). Combining the theoretical efforts on OSMOTIC PRESSURE by Van’t Hoff with his own ELECTROLYTIC DISSOCIATION theory opened up a new era in chemistry. For this revealing contribution, he received the Nobel Prize in Chemistry in 1903. Other credits go to his work on serum therapy (see [Figure A.93](#)).



Figure A.93 Portrait of Svante August Arrhenius (1859–1927). Svante Arrhenius attending the 1922 Solvay Conference “First Chemistry Conference.”

Arrhenius equation

[atomic, computational, quantum] Expression of the temperature dependence of the reaction rate k of a chemical reaction developed by SVANTE AUGUST ARRHENIUS (1859–1927), in 1889, based on the work by van't Hoff: $k = A_n e^{-(E_a/R)/T}$, with E_a the reaction ENERGY, R the universal GAS constant, T the ABSOLUTE TEMPERATURE, and A_n a unit equalizer constant, with n the order of the reaction. The reaction rate constant depends on the order of the reaction in value and units, for a first order reaction the units are s^{-1} , which can be interpreted as the number of collisions leading to a chemical reactions per SECOND. In DIFFUSION limited reactions the unit constant A_n will play a more significant role than under standard pressure and temperature kinetic reactions. In general PHYSICS and mathematics expressions, the term “Arrhenius equation” refers to an exponential DECAY with a straightforward exponential coefficient.

Arrhenius equation for electrolytic solution

[atomic, computational, quantum] Devised the following equation for the IONIZATION (α_c) of an ELECTROLYTE: $\alpha_c^2 [c]/(1 - \alpha_c) = k_i$, with $[c]$ the concentration, and k_i the ionization constant, which was shown to be independent of the concentration itself by the law of dilution of Ostwald.

Arrhenius number ($\alpha^* = E_0/RT$)

[atomic, energy, nuclear, thermodynamics] The relative aspect of activation ENERGY (E_0) with respect to THERMAL ENERGY, where R is the universal GAS constant, and T the temperature.

Asteroid

[astronomy] Galactic PROJECTILE constructed of solids (rocks and metals), ranging in size from millimeters to in the order of thousand kilometers. Asteroids orbit the SUN, mainly in what approximates circular ORBITS, primarily in a belt between the paths of MARS and JUPITER, with the largest identified asteroid named Ceres with size of approximately 1000 km. Asteroids in our SOLAR SYSTEM alone have quantities of millions. However, some asteroids also have larger trajectories around the Sun, intersecting the earth's orbit on occasion. In particular, every year in the first or second week of August, the EARTH traverses a cloud of asteroids, generating a few days of METEOR showers that light up the sky. In contrast, comets are made of GAS, ice, and rock. Comets also have a tail, made from vapors and GAS. There are only several thousand recorded and verified comets in our field of interest. Meteors are celestial objects that enter the Earth's ATMOSPHERE (see [Figure A.94](#)).



Figure A.94 Asteroid/meteor impact crater near Flagstaff, Arizona.

Asthenosphere

[acoustics, astronomy/astrophysics, chemical, electromagnetism, fluid dynamics, geophysics, mechanics, solid-state, thermodynamics] One layer of the crust of the planet's surface. The asthenosphere is primarily composed of a plastic medium. The asthenosphere is the underlying structural formation that provides the mechanism that supports SEISMIC ACTIVITY and volcanic activity (see [Figure A.95](#)).

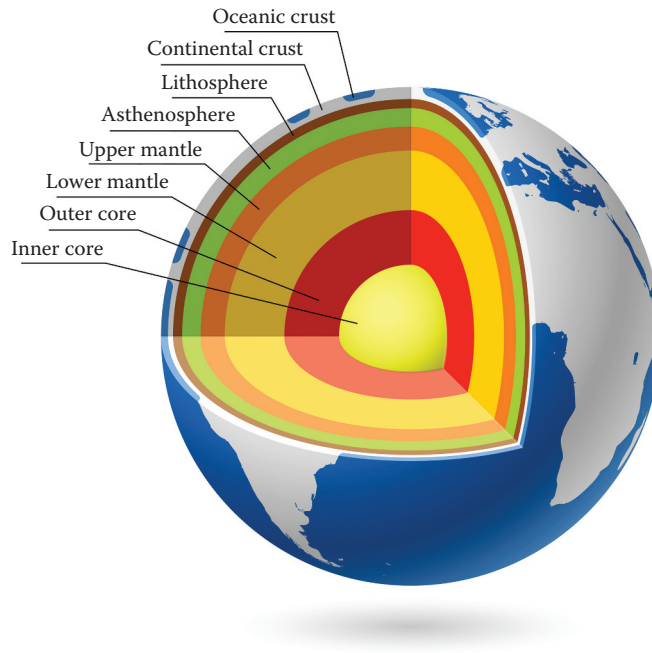


Figure A.95 Asthenosphere layer of the earth's crust.

Astigmatism

[optics] The formation of a focal IMAGE of a narrow bundle of light formed by a converging LENS generally results in two lines, that are both sharp images, respectively, which are orthogonal to each other in two planes carved out by the optical axis and perpendicular to each other, however, not necessarily in the same location on the optical axes, generally a finite DISTANCE apart. The images convolve into an oval shape proceeding down the optical path from the primary to the secondary focal line. The image formation yields a distance between the sharp projections of the two perpendicular lines. The distance between these two points on the optical axis is referred to as the astigmatic difference. There is, however, a circular image formed in between the two respective locations, but his image is not sharply defined but accepted as the FOCAL POINT. In the EYE, astigmatism represents a geometric contraction in one or more directions, resulting in a distorted image on the RETINA. The distorted image can be corrected by astigmatic lenses

that are defined with a cylindrical axis of correction to the normally applied symmetrical concave or convex lens surface (see Figure A.96).

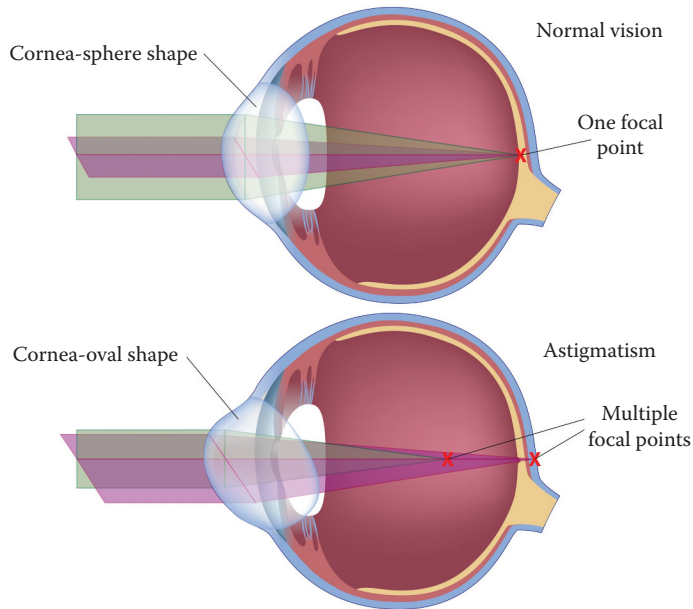


Figure A.96 Deviation of the optical axis by misshaped lens of the eye produces a distortion of the image formed on the retina known as “astigmatism.”

Astronomical units (AU)

[general] The average DISTANCE from the EARTH to the SUN: $1\text{AU} \cong 1.5 \times 10^{11}\text{ m}$.

Astrophysics

[astronomy, astrophysics, computational, energy, general, nuclear, quantum] Science of galactic entities, more specifically their characteristics such as ELECTROMAGNETIC emanation, MAGNETIC FIELDS, and magnetic interactions between PLANETS, SOLAR SYSTEMS, and GALAXIES; TEMPERATURE, COMPOSITION, WEIGHT, GRAVITY and GRAVITATIONAL INTERACTIONS, ORBIT, and places with respect to other galactic bodies or groupings (e.g., galaxies) are also referred to as the PHYSICS of ASTRONOMY. In addition in astrophysics, theoretical, and mathematical concepts are used to make predictions and derive mechanical properties of these galactic bodies without the ability to stage controlled experimental investigations. One of the many topics of interest is celestial MECHANICS (e.g., KEPLER’S LAW). Studying the spectral emissions of remote stars, for instance, can provide information about the GRAVITATION field strength and field line distribution based on the observed ZEEMAN EFFECT. Certain STARS have revealed gravitation forces in the order of several thousand Gs. Other interests of astrophysics are related to forming a model of how the EARTH came to existence and how the global environment is shaped the way it is (e.g., SEASONS, CIRCADIAN RHYTHM, THERMAL HYSTERESIS, FLUID pathways [wind and rivers] and indirectly impacting our daily WEATHER). Additional information is revealed about particulate (i.e., nuclear) and ELECTROMAGNETIC RADIATION, which provided early documented data on ELEMENTARY PARTICLES and the range of the ELECTROMAGNETIC SPECTRUM.

Atmosphere

[general] The earth's atmospheric composition is made up of the following components in the lower layer: nitrogen (N_2 , 78.08%), oxygen (O_2 , 20.09%), argon (Ar, 0.9%), carbon dioxide (CO_2 , 0.03%), neon (Ne, 0.002%), helium (He, 0.0005%), methane (Me, 0.0005%), next to water VAPOR and several chemicals resulting from environmental pollution (see [Figure A.97](#)).

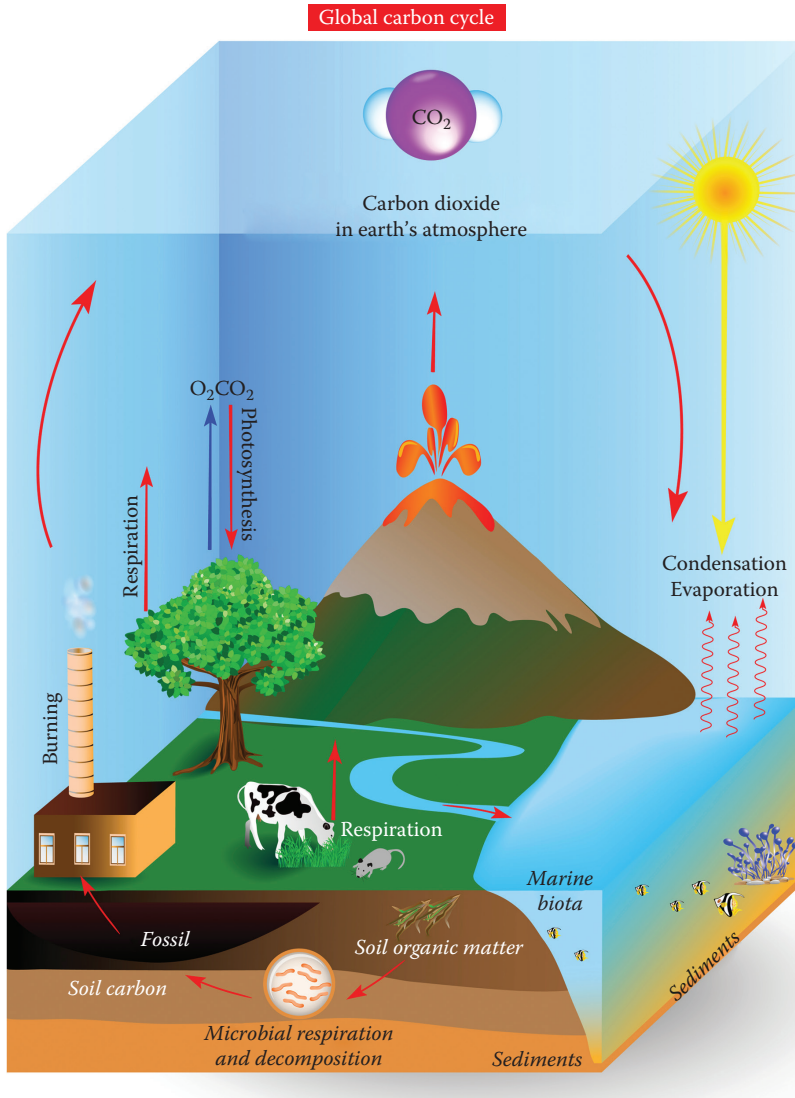


Figure A.97 Drawing of the composition of the atmosphere, specifically geared to the carbon cycle in carbon oxidation (metabolic activity in biology and fossil-fuel burning) with the reconstitution in pure oxygen for consumption and oxidation (i.e., exothermic reaction).

Atmosphere, unit (atm)

[general] The unit ATMOSPHERE was indirectly introduced in 1643 by the Italian scientist EVANGELISTA TORRICELLI (1608–1647). The atmosphere is still in common use next to the bar ($1\text{ bar} = 10^5\text{ Pa}$) and millimeters mercury ($1\text{ atm} = 760\text{ mmHg}$), and in some countries pounds per square inch ($1\text{ PSI} = 6.8948 \times 10^3\text{ Pa}$) but was replaced by Pascal ($1\text{ atm} = 1.01325 \times 10^5\text{ Pa} = 101.325\text{ kPa}$) in based on the efforts by BLAISE PASCAL (1623–1662).

Atmospheric layers

[energy, fluid dynamics, geophysics] The ATMOSPHERE is demarcated into various layers with respect to the most significant physical parameters within a specific range of altitudes. The various atmospheric layers are (starting at sea-level outward): TROPOSPHERE, STRATOSPHERE, MESOSPHERE, THERMOSPHERE, EXOSPHERE, IONOSPHERE, and also includes the MAGNETOSPHERE (see [Figure A.98](#)).

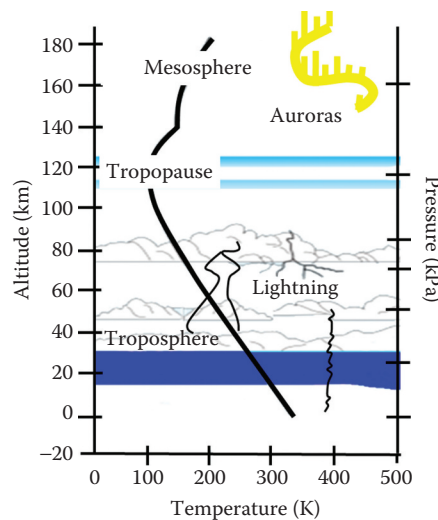


Figure A.98 Detailed diagram outlining the various established atmospheric layers with their respective nomenclature and the reigning temperature ranges.

Atmospheric physics

[astrophysics, atomic, energy, fluid dynamics, general, geophysics] Field of PHYSICS dealing with physical phenomena in the EARTH'S ATMOSPHERE. Specific phenomena of interest in the LOWER ATMOSPHERE pertain to METEOROLOGY and CLIMATOLOGY. Additional interests in the UPPER ATMOSPHERE or IONOSPHERE are in relation to communication and the long-term influences on SEASONAL as well as DIURNAL variations. Examples of the latter include the environmental impact of the OZONE LAYER (see [Figure A.99](#)).

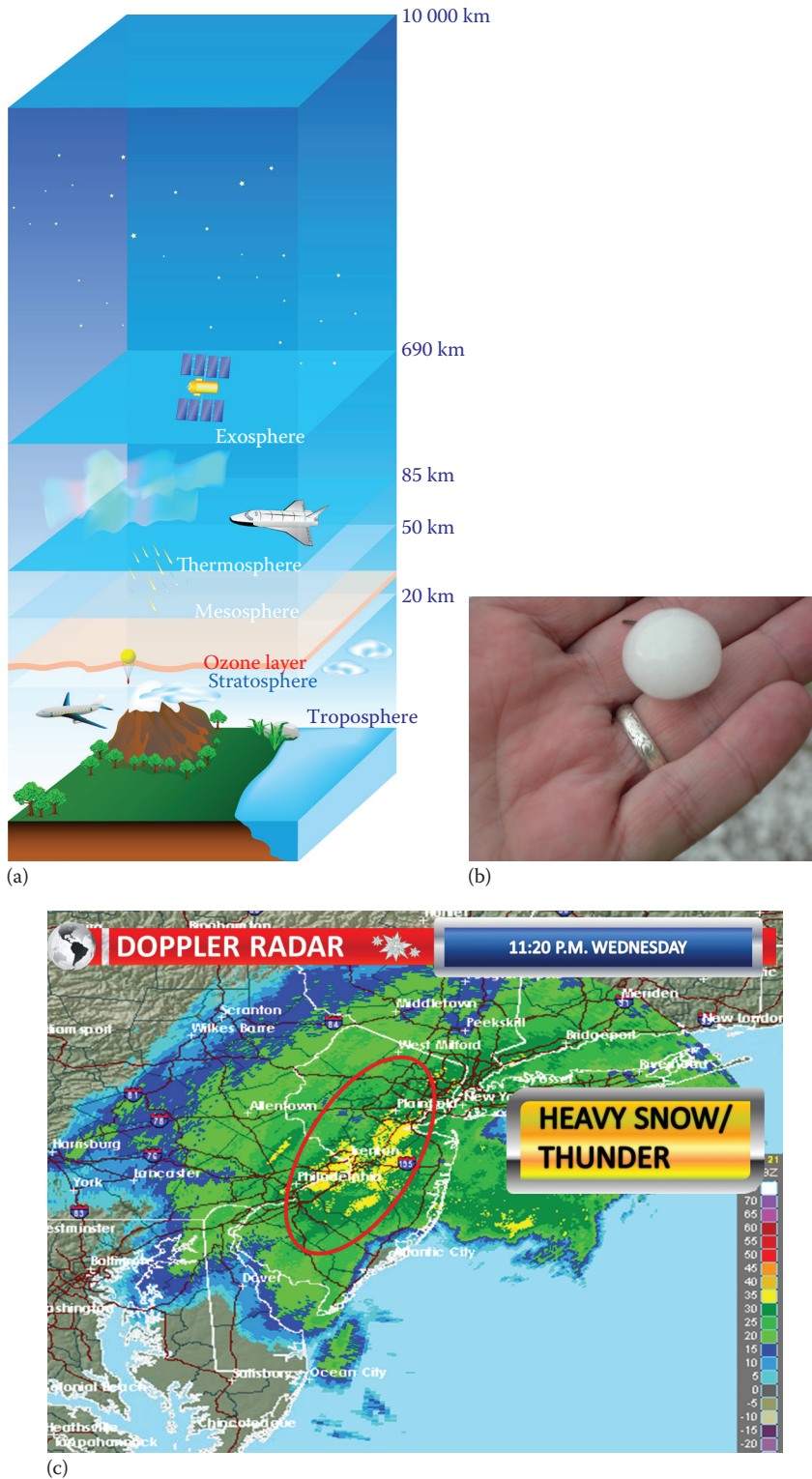


Figure A.99 (a) Diagram of distinguishable layers in the atmosphere with their characteristic features. (b) Image of hail precipitation occurring under specific meteorological conditions. (c) Weather conditions obtained by means of Doppler imaging systems designed by atmospheric physicists.

Atmospheric pressure

[fluid dynamics, general] (standard), Pressure measured against atmospheric pressure, also called “GAUGE PRESSURE.” VACUUM conditions are frequently expressed as negative pressure. Atmospheric pressure is generally the weight of the column of AIR per unit area $P = \int \rho(r)gdr$ at a certain location with respect to sea-level in altitude (dr), where g represents the GRAVITATIONAL ACCELERATION and $\rho(r)$ the atmospheric density as a function of the DISTANCE to sea level into outer space, which is highly variable over the distance (r) from the surface to the outer outer-layer or IONOSPHERE. The pressure will also change because of geo-physical conditions such as temperature and conglomerations of air layers (*also see* WEATHER).

Atom

[atomic, general, nuclear, quantum, solid-state] Smallest self-contained matter unit that has all the primary and secondary characteristics of the MACROSCOPIC ELEMENT, which is embedded in the name that is derived from the Greek word *atomos* (ἄτομος), meaning indivisible. The concept of a discrete structure of MATTER dates back to the Greek philosophers, specifically LEUCIPPUS (fifth century BC) from ancient Greece, who produced the first documented hypothesis of an elementary PARTICLE that contains all the characteristics of a larger assembly object in approximately 450 BC. Later in 420 BC DEMOCRITUS (c. 460–370 BC) made a similar statement in this regard. A quantitative validation of this hypothesis was not obtained until approximately the year 1790 when ANTOINE-LAURENT DE LAVOISIER (1743–1794) submitted that total mass is conserved in any CHEMICAL REACTION no matter what physical shape (LIQUID, SOLID, and GAS). Based on these and other observations, JOHN DALTON (1766–1844) postulated the first chemical reaction statement in 1808, including that every pure chemical is made up of same elementary components, forming the element foundation. The ELEMENTS themselves were also considered to be composed of a unique grouping of identical components: atoms. The designation “element” however was conceived long before then, more precisely in 1661, introduced by ROBERT BOYLE (1627–1691). Additional contributions from AMEDEO AVOGADRO (1776–1856) in 1811, who concluded that not all elements consist of single atoms, some are biatomic forming MOLECULES, which provided supporting evidence with regard to the chemical mass statements made by Dalton. Avogadro’s work led to the postulation of the AVOGADRO’S NUMBER quantifying the mass of elements, yielding the atomic mass or ATOMIC WEIGHT as a relative number. The atomic mass for the documented atoms ranges from 1 (HYDROGEN) to 250 as a rounded-of integer, (mass number: A). The atomic structure was further defined by the work of JOSEPH JOHN THOMSON (1856–1940) with the discovery of the electron in 1897. Refinements were made by NIELS HENRIK DAVID BOHR (1885–1962) based on his description of the QUANTUM model of the HYDROGEN ATOM in 1915. ERNEST RUTHERFORD (1871–1937) along with HANS GEIGER (1822–1945) and ERNEST MARSDEN (1889–1970) and provided ALPHA PARTICLE scattering evidence in the period 1908–1913 making way for the BOHR ATOM model by providing proof of the quantization of electronic ENERGY levels. The alpha particle SCATTERING experiments of Rutherford, Geiger, and Marsden revealed that the nucleus has to be of relatively large mass in comparison with the electrons and the nucleus would have a POSITIVE CHARGE. It was concluded that the (relative minority of) alpha particles were recoiled by ELASTIC COLLISION with the nucleus, not by the electrons (*also see* BOHR ATOM). In 1913, HENRY (HARRY) GWYN JEFFREYS MOSELEY (1887–1915) delivered experimental proof of quantized X-RAY emission, conforming the energy exchange (CONSERVATION OF ENERGY) between two electron levels ($E(n_i)$) in the form of photons with a specific WAVELENGTH (λ) matching an energy content: $E_{\text{photon}} = E(n_2) - E(n_1) = h\nu = hc/\lambda$, with associated PHOTON frequency $\nu = c/\lambda$, where c is the speed of light and h is PLANCK’S CONSTANT. Many of the transitions were documented as BREMSSTRAHLUNG defined, for instance, by the BALMER, LYMAN, and PASCHEN SERIES. The work of ERWIN SCHRÖDINGER on WAVE MECHANICS published in 1927 provided additional background for the development of the atomic model. Specifically, Schrödinger’s work led to the introduction of three QUANTUM NUMBERS for the electron in orbit: n the PRINCIPAL QUANTUM NUMBER ($E_n = -(2\pi^2k_0^2e^4m_eZ^2/h^2)(1/n^2)$, where Z is the ATOMIC NUMBER, m_e is the electron mass, e is the ELECTRON CHARGE, h is PLANCK’S CONSTANT, and k_0 the Coulomb force constant), and two ORBITAL ANGULAR MOMENTUM QUANTUM NUMBERS: the ORBITAL ANGULAR MOMENTUM QUANTUM NUMBER ℓ for the MAGNITUDE

($m_{\text{angular}} = [\ell(\ell + 1)]^{1/2} \hbar$, where $\hbar = h/2\pi$) and the ORBITAL MAGNETIC QUANTUM NUMBER m_ℓ for the magnitude of the projection in the direction of a specific axis ($L_{\text{orbital angular projection}} = m_\ell \hbar$). The atom has a core made up of PROTONS and NEUTRONS providing the ATOMIC NUMBER (Z) and electron charge due to the difference between the number of positive protons and the balance of electrons in orbit around the NUCLEUS. The core (nucleus) has no specific role in the physical description of chemical interaction and quantum structure apart from the fact that it describes the energy field (i.e., POTENTIAL WELL) that confines the electrons. The nucleus is binding the electrons by COULOMB FORCE, but in order for the electrons not to spiral into the opposite charge nucleus the electrons will need to be in rotational MOTION as described by Rutherford, and supported by the work of Schrödinger. The size of the nucleus was derived from the ALPHA PARTICLE collisions. In the collision the kinetic energy (KE_α) of the alpha particle with mass m_α and velocity v_α needs to convert into potential energy (PE_α) described by the Coulomb energy. This will take place at the radius (R) of the nucleus described as: $KE_\alpha = (\pi/2) m_\alpha v_\alpha^2 = PE_\alpha = 4(k_0 Z e^2 / R)$, yielding a nuclear size in the order of 10^{-14} m, while the atom has dimensions in the order 10^{-10} m leaving a significant amount of empty space. The size of the average atom was derived experimentally in the late 1800s simply from volumetric calculations. When OIL is allowed to spread out on a water surface, the final result will be a single molecular layer, spread out over a surface area that can be measured. Relating this area to the initial volume of oil will give a reasonable approximation of the thickness and hence the size of the molecule. Other means of deriving atomic size (L_{specific}) applied to atomic gases rely on AVOGADRO'S NUMBER (N_a) for the VOLUME (V) of one MOLE (M_m) of GAS with mass M_m and density: $\rho = M_m/V = M_m/N_a L_{\text{specific}}^3$ (see Figure A.100).

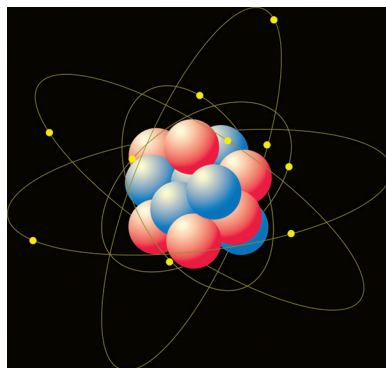


Figure A.100 Hypothetical model of the structure of an atom.

In property classification, the atom is the smallest quantity of a single element that has all the characteristics that can be attributed to any large quantity of this element and verified against scientific standards.

Atomic bomb

[general, nuclear, solid-state] Nuclear fuel device using URANIUM ($^{238}_{92}\text{U}$) or PLUTONIUM ($^{239}_{94}\text{Pu}$) (both can be derived from uranium), conceived by ROBERT J. OPPENHEIMER at the Los Alamos, NM research facility with the assistance of NIELS BOHR, JAMES CHADWICK, OTTO FRISCH, ENRICO FERMI, and RICHARD P. FEYNMAN under direction of General Groves. The atomic self-sustaining FISSION reaction for the unstable ISOTOPE U-235 initiated by a NEUTRON proceeds as follows: $^1_0\text{n} + ^{235}_{92}\text{U} \rightarrow ^{236}_{92}\text{U}^* \rightarrow ^{145}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^1_0\text{n} + E_{\text{fission}}$, leaving three neutrons to initiate other fission reactions each. Only 0.72% of all uranium occurring as $^{235}_{92}\text{U}$, whereas $^{238}_{92}\text{U}$ (99.27% of all uranium in natural state) is stable and a TRACE occurrence of $^{234}_{92}\text{U}$. Both barium and krypton have a BINDING ENERGY of approximately 8.5 MeV for the 145 and 92 nucleons, respectively, whereas uranium has a binding energy of 7.6 MeV for the 235 NUCLEON, leaving approximately 216 MeV for the fission ENERGY of one uranium ATOM. This reaction was postulated by Leo Szilard, a Hungarian

physicist, leading to the development of the atomic bomb in 1941. The nuclear reaction requires a critical mass of greater than 10 kg to be able to support sustained NUCLEAR FISSION. The critical mass is accomplished by forcefully joining two segments of subcritical mass under explosive conditions (detonation). At the moment, the critical mass is exceeded the fission process becomes a self-sustaining CHAIN REACTION fueled by emitted neutrons, while at subcritical mass too many of the neutrons that are released will exit from the uranium or plutonium and the chain reaction is not sustained (see [Figure A.101](#)).

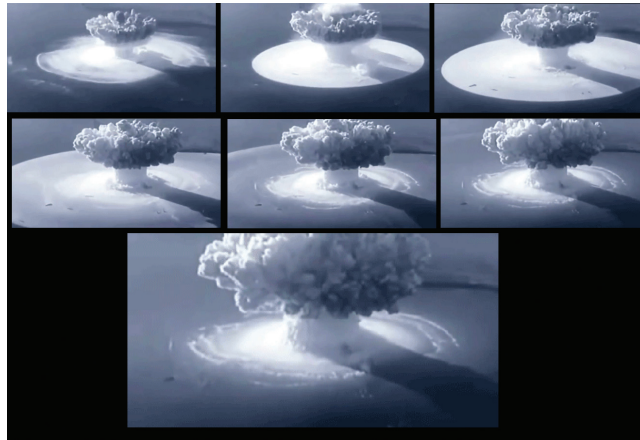


Figure A.101 Image of the explosion of an atomic bomb in atmosphere.

Atomic clock

[general] Clock based on the transition between the lowest ENERGY state to the second-lowest state of cesium-133 triggered by the absorption of incident ELECTROMAGNETIC RADIATION. The transition generates a frequency signature that is defined and measurable to an accuracy of 10^{-13} , or defining the second as 9,192,631,770 oscillations on EM RADIATION resulting from the transition. This definition/standard holds true with precision of 1 SECOND deviation over a period of 300,000 years.

Atomic emission

[general, nuclear, optics] The emission of a PHOTON from the (negative-) ACCELERATION of an EXCITED atomic ELECTRON returning to its GROUND STATE. The ATOM can be raised to an excited state with an ENERGY equal or greater than the energy difference between the orbital states (i.e., the BOHR ATOM model). The excitation may result from COLLISION or ELECTROMAGNETIC RADIATION. This process is the primary mechanism of action for the operation of LASER.

Atomic energy

[general, nuclear, solid-state] An ATOM stores ENERGY from the electrical attraction between the positive NUCLEUS and orbiting negative ELECTRONS (the BOHR ATOM model). The electrical force described by COULOMB FORCE ($F_e = k_0(Ze)(e)/r^2$) equals the CENTRIPETAL FORCE ($F_c = m_e(v^2/r)$) of the orbit for equilibrium to be maintained. The GROUND-STATE ENERGY of each ELECTRON ORBITAL MOTION identified by the PRINCIPAL QUANTUM NUMBER: n , is expressed as: $E_0 = -\left(2\pi^2 k_0^2 e^4 m_e / h^2\right) \left(Z^2 / n^2\right)$.

Atomic force microscope (AFM)

[biomedical, general, solid-state] Imaging device that maps the surface FORCE and surface elevation by means of electrical attraction between a nanoprobe and the ATOMIC and MOLECULAR structure of the MEDIUM under investigation using the COULOMB FORCE to generate a signal that is represented as a function of the two-dimensional location of the probe. The AFM can typically measure forces better than 1 fN . The concept of the AFM is based on the principles of the scanning tunneling microscope (STM) developed by the scientists GERD BINNIG (1947–) and HEINRICH ROHRER (1933–2013), both from Switzerland, working for IBM. The AFM provides resolution at least a thousand times greater than optical diffraction limit. The AFM moves a hyperfine needle over a surface by means of piezoelectrical OSCILLATION. The concept resembles braille reading to an extent. Generally, the mechanical MOTION of the CANTILEVER is recorded by means of a reflected laser beam; the position of the reflected ray on a photo-array correlates linearly with the probe's motion in response to the scan across the surface relief. Under these operating conditions, the use of a stylus with tip size of several nanometer the horizontal resolution is approximately 0.2 nm , and progressively improving, while the vertical resolution is better than 0.1 nm . The topography can be determined in full-contact/DRAW mode, or in tapping mode, respectively. The tapping mode relies on a DRIVEN DAMPED HARMONIC OSCILLATOR. The AFM resolution is in the order of single ATOM vertically. The resolutions differs due to the lateral use of piezo drives (more coarse) and springs vertically. The electronic feedback on the piezo deflection allows MEASUREMENT of electrical forces between the probe and the surface of less than 1 fN . After SIGNAL PROCESSING an IMAGE is created on atomic scale showing the force distribution and hence the localized (molecular-) material properties (see [Figure A.102](#)).

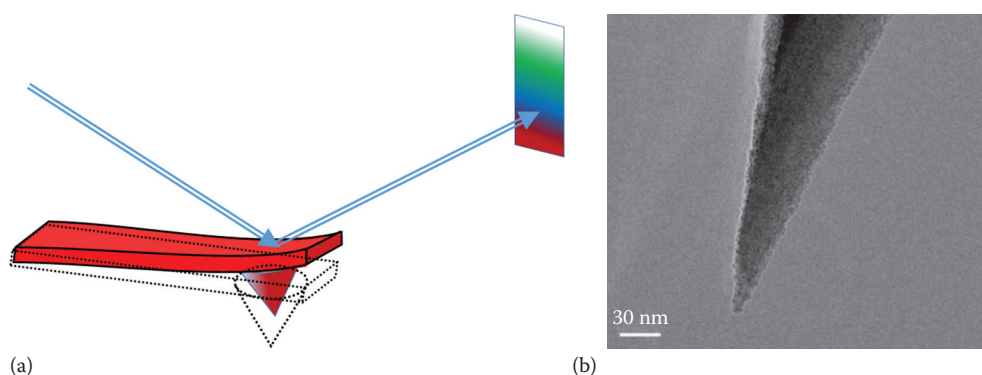


Figure A.102 (a) Mechanism of operation of the atomic force microscope. (b) Electron microscopy image of the deflecting needle tip (PointProbe[®]) used in the AFM.

Atomic line spectra

[atomic, chemical, energy, mechanics, optics, quantum, thermodynamics] Emission lines of atomic excitation (see LINE SPECTRA).

Atomic mass, unit (u)

[general, nuclear, solid-state] One twelfth of the mass of standard CARBON (^{12}C); $1u = 1.660540 \times 10^{-27}\text{ kg}$.

Atomic model, Bohr

[atomic] See BOHR ATOMIC MODEL.

Atomic model, Rutherford

[atomic] See **RUTHERFORD MODEL**.

Atomic model, Thomson

[atomic] See **THOMSON ATOMIC MODEL**.

Atomic number (Z)

[atomic, general, nuclear] The quantity of protons in the **NUCLEUS** of an **ATOM**, also providing the total **POSITIVE CHARGE**. The concept was introduced in 1913 by **NIELS HENRIK DAVID BOHR** (1885–1962) with assistance from **HENRY (HARRY) GWYN JEFFREYS MOSELEY** (1887–1915).

Atomic weight

[atomic, nuclear] See **ATOMIC MASS**.

ATP (adenosine triphosphate)

[biomedical, chemical, energy, thermodynamics] Biological renewable **CHEMICAL ENERGY** source. ATP is a chemical substance that can exchange a single phosphate molecule under hydrolysis with release of **ENERGY**. This process can easily be reversed by means of external energy, either released from metabolic process and, under certain conditions, by means of solar **RADIATION**. The average energy release is 7.3kcal/mole: $\text{ATP} + \text{H}_2\text{O} \rightleftharpoons \text{ADP} + \text{phosphate} + \text{energy}$, producing **ADENOSINE DIPHOSPHATE (ADP)**. The depleted ATP, that is, ADP can quickly be replenished through the phosphate release from stored creatine-phosphate (specifically in **MUSCLE**) next to **GLYCOGEN** (70% stored in muscle, 20% in the **LIVER**, and the remaining 10% floating freely in **BLOOD** to provide an emergency backup). In the biological **CELL**, there is a secondary and tertiary chemical energy process produced by **NADH** (nicotinamide adenine dinucleotide: **FAD**) in the form of $2\text{NADH} + 2\text{H}^+ + \text{O}_2 \rightleftharpoons 2\text{NAD}^+ + 2\text{H}_2\text{O} + \text{energy}$, respectively, $2\text{FADH}_2 + \text{O}_2 \rightleftharpoons 2\text{FAD} + 2\text{H}_2\text{O} + \text{energy}$ (flavin adenine dinucleotide: **FAD**) (see [Figure A.103](#)).

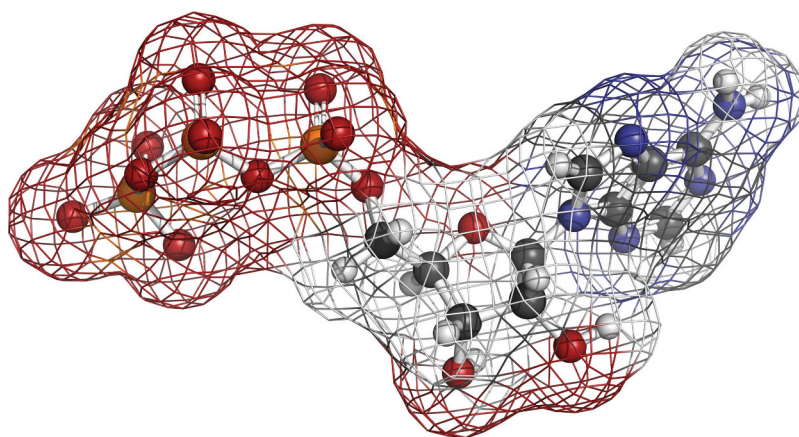


Figure A.103 Graphical interpretation of the adenosine triphosphate (ATP) molecule.

ATPases

[biomedical, energy, thermodynamics] Active ionic reactions or ION transfer (in biological systems) that consume the ENERGY from ATP conversion. ATPases are proteins that have been conserved throughout evolution and are grouped in three categories: P-type, V-type, and F-type. The P- and V-type ATPases are involved in processes where the ATPases consume energy, whereas the F-type ATPases provides a major source of ADENOSINE TRIPHOSPHATE (ATP, a nucleoside triphosphate renewable energy source used in cells as a coenzyme). The P-type ATPases include the cellular MEMBRANE ion gradient maintenance through the Na^+/K^+ ATPases as well as Ca^{2+} ATPases, specifically in MUSCLE and participates in the phosphorylated intermediate steps of the phosphor reactions. The V-type is involved in the regulation of the acidity (pH) of the CELL, in particular the accumulation of H^+ in the vesicle lumen. ATPase F-type drives the ATP synthase by means of the inner mitochondrial membrane. In this process, under aerobic conditions, a single GLUCOSE molecule is converted in pyruvate molecules in two-to-one ratio, yielding 2 ATPs; where subsequently the respective pyruvate molecules can produce up to 32 TP molecules from ADENOSINE DIPHOSPHATE (ADP) in a citric ACID cycle within the MITOCHONDRIA. The general role of ATPases is in the recovery process after an ACTION POTENTIAL has been generated and the CELL MEMBRANE needs to brought back to equilibrium NERNST POTENTIAL. In response to the uncontrolled K^+ efflux after the action potential that opens the ion-gates in the membrane for free migration, the cell reaches hyperpolarization. The ATPases subsequently initiate the Na^+/K^+ -pump mechanism to regulate the inner- and extracellular ion concentrations, moving three (3) Na^+ ions out of the cell against two (2) K^+ ions. The Na^+/K^+ -pump ACTIVITY is regulated by means of membrane receptors that respond to fluctuations in cyclic adenosine monophosphate (cAMP, or 3'-5'-cyclic adenosine monophosphate; a second membrane messenger molecule). In addition, hormones such as insulin, thyroid-hormone, and aldosterone increase the Na^+/K^+ -pump mechanism, whereas dopamine in the KIDNEY in particular inhibits the activity (see [Figure A.104](#)).

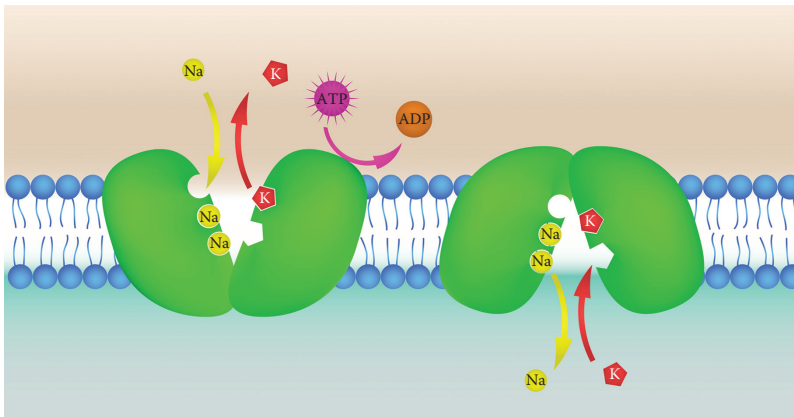


Figure A.104 The role of ATP in the membrane energy exchange supporting active processes, such as the sodium-potassium pump.

Atwood, George (1746–1807)

[general, mechanics] A British physicist known for his computational work on MECHANICS. He conceived a machine that can be used to experimentally determine accelerated MOTION (i.e., GRAVITATIONAL ACCELERATION), aptly named after him as the Atwood machine. The Atwood machine uses a PULLEY system with two weights suspended on either side from a string hanging over the pulley that remains in balance if both weights are equal, when a mass is added to either sides, the system of weights will perform linear accelerated motion and can be used for validation (see [Figure A.105](#)).

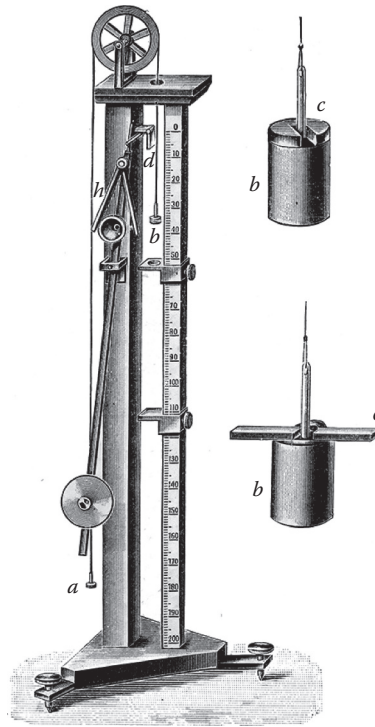


Figure A.105 Drawing of the Atwood machine, as designed by George Atwood (1746–1807) for testing of mechanical principles.

Auger, Pierre Victor (1899–1993)

[atom, energy, general, solid-state] A nuclear physicist from France, who started out working under JEAN PERRIN (1870–1942) on the PHOTOELECTRIC EFFECT. Pierre Auger provided elementary insight in the interaction of electrons on an atomic level. In electron microscopy, the AUGER ELECTRONS captured from SCATTERING events are named after him (see [Figure A.106](#)).

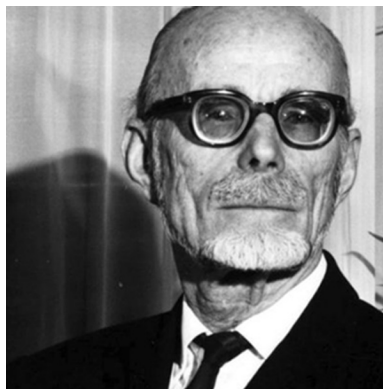


Figure A.106 Pierre Victor Auger (1899–1993).

Auger effect

[atomic, nuclear, solid-state] Atomic or molecular electronic transition from higher to lower energetic state in which another electron (Auger electron) is released and no RADIATION is emitted. First described by PIERRE AUGER (1899–1993). This process usually takes place in high energetic electron ORBITS close to the NUCLEUS and is primarily associated with the interaction of X-RAY with MATTER. Auger transitions can be extremely fast; one example is the COSTER–KRONIG TRANSITION. The radiationless transit PROBABILITY is described mathematically as $w_{fi} = \hbar^{-2} |D_{\text{direct}} - E_{\text{exchange}}|^2$ (see Figure A.107).

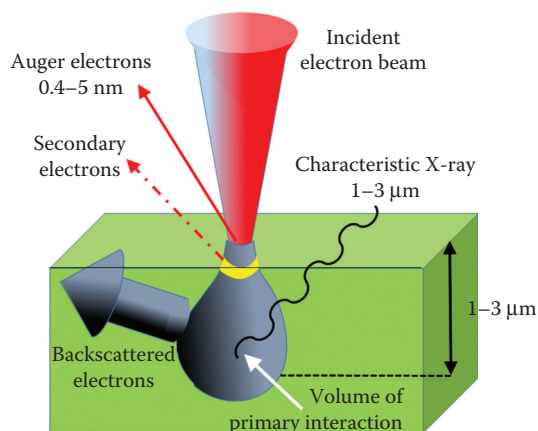


Figure A.107 Graphical representation of the electron interaction with a conductive medium, releasing Auger electrons from the surface with reduced energy.

Auger electrons

[atomic, imaging] Scattered electrons used to provide ENERGY information about the structural configuration of an atomic structure under electron microscopy imaging. Incident primary electrons interact in many different ways: IONIZATION with release of secondary electrons, REFLECTION, REFRACTION, LUMINESCENCE, and desorption (process of molecular breakdown) next to the AUGER EFFECT. During the interaction of primary electrons from the electron beam inner electrons may be ejected, creating a vacancy that requires filling with an electron from a lower energy (higher) orbit. The RADIATION emission resulting from the Auger electron is characteristic for the ATOM in question and can hence be used for atomic and molecular specification of the object under investigation.

Aurora

[general] A stream of IONS, caused by SOLAR FLARES, accelerating in the Earth's ATMOSPHERE under GRAVITATIONAL pull near the POLES. The ions travel through space and become entangled in the EARTH'S GRAVITATIONAL FIELD to be drawn into the NORTH AND SOUTH POLES. The charges (q) moving with

VELOCITY ($\vec{v}$) are subject to NEWTON'S THIRD LAW and will experience a FORCE (F_B) resulting from the MAGNETIC FIELD ($\vec{B}$). The force on the charge is, with AMPÈRE'S LAW, the magnetic equivalence of the LORENTZ FORCE, written as: $F_B = q\vec{v} \times \vec{B}$, causing the ION to move in a direction that follows from the RIGHT-HAND-RULE, migrating in a circular MOTION (more specifically: FLEMING'S RIGHT-HAND RULE). The force is perpendicular to the MAGNETIC FIELD direction while the force is also perpendicular to the velocity. The magnetic force will continuously attempt to balance against the CENTRIPETAL FORCE: $F_C = mv^2/R$, where m is the mass of the PROJECTILE and R designates the radius of curvature of the circular MOTION. The charge will however lose KINETIC ENERGY because of external forces (e.g., FRICTION and collision) causing it to slow down, which results in a spiraling motion toward to EARTH'S surface. The phenomenon observed in the NORTH POLE (AURORA BOREALIS) is generally more impressive than on the SOUTH POLE (AURORA AUSTRALIS). As the ions are accelerated and collide with atmospheric molecules, they emit ELECTROMAGNETIC RADIATION that causes the polar sky to light up with a stream of colored light at approximately 95 km altitude. The phenomenon at such high altitude explains why it is visible down to the 60th LATITUDE and on occasion as far down as to the 30th latitude (see Figure A.108).

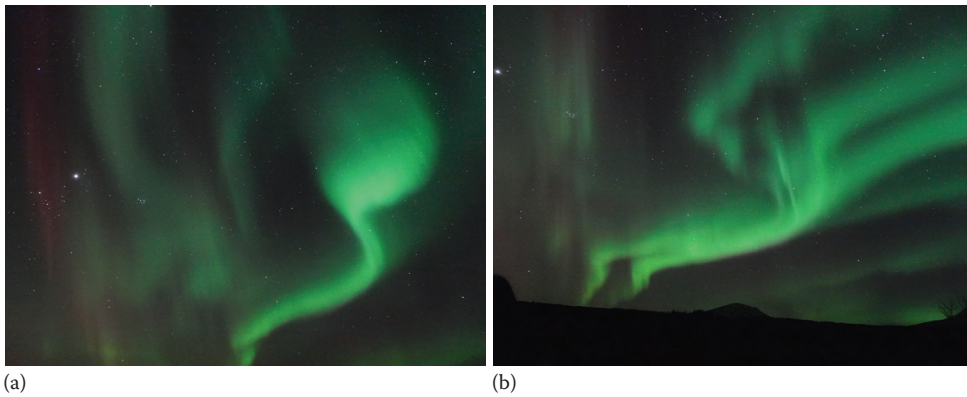


Figure A.108 (a,b) Aurora borealis. (Courtesy Joe Morris.)

Aurora Australis

[astrophysics, atomic, energy, geophysics] AURORA on the SOUTH POLE, also SOUTHERN LIGHT (see AURORA).

Aurora Borealis

[astrophysics, atomic, energy, geophysics] AURORA on the NORTH POLE, also NORTHERN LIGHT (see AURORA).

Auscultatory method for blood-pressure determination

[acoustics, biomedical, fluid dynamics] From Latin: auscult, meaning "listen." It is a method using a SPHYGMOMANOMETER in combination with a stethoscope, where the former is used to measure compression force on an artery in the arm with a mercury column indicating the applied pressure in mmHg while listening for the SOUND made by BLOOD seeping through a small slit as the artery is opened up in hemo-static balance with the applied external pressure from an inflated (RIVA-ROCCI) CUFF around the arm that is

slowly emptying out. The “listening” applies to the Korotkov sounds made when the blood is forced through the narrow opening acting as letting AIR out of a balloon making a screeching sound, in this case only intermittently when the SYSTOLIC PRESSURE exceeds the externally applied pressure (see [Figure A.109](#)).



Figure A.109 Measuring blood pressure based on the audible sounds resulting from the periodic blood flow (acting like a kazoo; toy blow instrument) generating mechanical vibrations when blood is forced through a pressurized closed venturi (Korotkoff sounds). The audible aspect is referred to as the “auscultatory method,” in contrast to, for instance, Doppler flow recordings.

Autocorrelation

[computational, theoretical] A process of mathematically identifying a SIGNAL with respect to itself, past and future events. In comparison, cross-correlation compares a signal to a “universal” standard. Correlation theory is concerned with quantifying the similarity between two signals. It has wide application, ranging from radar signal processing to character recognition. The procedure of cross-correlating the probing, incident signal with the measured signal in order to highlight time-lag between the two signals for feature recognition with the medium the measured signal has returned from. Specifically, the spectral analysis of the two signals is imbedded in the resolved harmonics of the autocorrelated signal. The autocorrelation process is performed as a function of time, thus providing time resolved information, specifically with respect to nonperiodic functions. The defined (in most cases “electronic”) process (X) changes with time and holds the input or initial value as well as the returned value at different points in time (time-lag between input and MEASUREMENT: time t and time $t - \tau$, respectively). The signal will have a mean value at time t : μ_t and associated variance: σ_t^2 (with standard deviation σ_t). The autocorrelation between the events recorded at times t and $t - \tau$ is defined by $R(t, t - \tau) = E[(X_t - \mu_t)(X_{t-\tau} - \mu_{t-\tau})] / \sigma_t \sigma_{t-\tau}$ (also referred to as the “autocorrelation coefficient,” due to the NORMALIZATION $1/\sigma_t \sigma_{t-\tau}$, and the fact that all measurements are taken against the mean μ_t), where $E[(X_t - \mu_t)(X_s - \mu_s)]$ expresses the “expected value” operator. Alternatively, the correlation between two variables x (with mean μ_x and standard deviation σ_x) and y (with mean μ_y) expressed similarly as $R(x, y) = \sum_N (x_i - \mu_x)(y_i - \mu_y) / \sigma_x \sigma_y$. Generally, the autocorrelation process needs to be performed within a spectral range, depending on the source and the application as well as the type of information sought after. The value of $R(t, t - \tau)$ falls in the range $[1, -1]$, where $R(t, t - \tau) = 1$ (respectively $R(x, y) = 1$) indicates perfect correlation and $R(t, t - \tau) = -1$ references total anti-correlation. When considering a signal that can be described as a well-defined function $f(t)$ the [continuous] autocorrelation process becomes the convolution (*) between the function at time t with lag τ expressed as $R_{ff}(\tau) = (f(t) * f^*(-t))(\tau) = \int_{-\infty}^{\infty} f(t + \tau) f^*(t) dt = \int_{-\infty}^{\infty} f(t) f^*(t - \tau) dt$, where f^* is the complex conjugate. The autocorrelation process also allows for tracking through time by artificially increasing

the time-lag in the correlation process, hence specifically increasing the temporal resolution, which may be limited by the device specifications or based on the preferred “distance (x)” the collected signal is returning from. In this case, the DISTANCE can be physical depth, linked to TIME (t) by the speed of propagation (v) as $x = vt$, or is the delayed signal resulting from, for instance, atomic RESONANCE. The spatial information retrieval is used in OPTICAL COHERENCE TOMOGRAPHY and a variety of other tomographic imaging techniques, which employ the simultaneous identification of “resonance” characteristic recovery for identification of atomic, energetic, and anatomic details such as primarily used in ULTRASOUND, and with selective applications for PET, and MRI, for resolution enhancement. The autocorrelation process also defines the “visibility” concept, how well can two signals be separated, that is, location information as well as time information resolved. The visibility is defined as the difference in intensity between the highest AMPLITUDE and lowest amplitude.

Autocorrelation function

[computational] It represents the degree to which the field correlates to itself at an earlier time: $\gamma(\tau) = E(t)E(t-\tau)/E(t)^2$, where $E(t)$ represents the “expected value” operator for the function or SIGNAL as a function of time, meaning the weighted average of all possible values. This weighted average can be acquired from multiple recurring measurements on the repetitive signal, generally adhering to a PROBABILITY distribution, for instance, NORMAL DISTRIBUTION or Gaussian (see AUTOCORRELATION).

Autocrine signaling

[biomedical, chemical, energy] Cellular secretion of soluble factors that regulate the hemostasis and often also control the growth rate of the CELL.

Average binding energy ($E_{\text{bind, avg}}$)

[nuclear] The NUCLEAR BINDING ENERGY for a solid or a LIQUID is a constant, allowing the heat of vaporization to account for the binding energy. The heat of vaporization (Q) is the total amount of work required to generate n separate molecules by dissociation of m gram of liquid (or solid) substance, as provided by $E_{\text{bind, avg}} = Q/n = QM_0/m$, where $m = nM_0$, and M_0 is the mass of one molecule (see BINDING ENERGY).

Avogadro, Lorenzo Romano Amedeo Carlo (1776–1856)

[general] A physicist, engineer, and chemist from Italy; Count of Quaregna and Cerreto [Lorenzo Romano Amedeo Carlo Avogadro di Quaregna e di Cerreto]. In 1811, Amedeo Avogadro made a statement introducing the word and definition “molecule.” The statement contains two hypothesis that are generally accepted as true. The first hypothesis is that gaseous media can exist in molecular form. The second hypothesis

verbalizes that equal volumes of different gasses in molecular form under the same pressure and temperature will consist of the identical number of molecules, that is, **AVOGADRO'S LAW** (see [Figure A.110](#)).



Figure A.110 Representation of Lorenzo Romano Amedeo Carlo Avogadro (1776–1856).

Avogadro's constant (N_A)

[atomic, biomedical, general, nuclear, thermodynamics] Standard for an arbitrary **ELEMENT** or chemical substance describing the quantity of atoms or molecules in a gram-molecular weight, respectively, *also* **AVOGADRO'S NUMBER**. The constant defining the number of moles of **GAS** in 1cm^3 under standard temperature (0°C) and pressure (1 atm) [STP]. $N_A = 6.022140857(74) \times 10^{23} \pm 1.8 \times 10^{16}$ (2011 definition). In addition, the Avogadro's number is associated with the **MOLE** as the number of atoms in a quantity of pure carbon-12, where 1 mole of ^{12}C weighs exactly 12 g, and contains Avogadro's number in atoms of carbon. This was defined by **AMEDEO AVOGADRO** (1776–1856) around 1811, following on the work of **JOHN DALTON** (1766–1844) in 1805.

Avogadro's law

[atomic, fluid dynamics, general, nuclear] Equal **VOLUMES** of different **GASSES** under equal **TEMPERATURE** and **PRESSURE** contain an equal amount of **MOLECULES**. Expressed by **AMEDEO AVOGADRO** (1776–1856) in 1811. This evolved in the definition of the **UNIVERSAL GAS CONSTANT** that states the number of any gaseous

molecules in a volume of 1 cm^3 under standard temperature ($0^\circ\text{C} = 273.15 \text{ K}$) and standard pressure ($1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa}$) [STP].

Avogadro's number (N_A)

[atomic, biomedical, general, nuclear, thermodynamics] Standard for an arbitrary ELEMENT or chemical substance describing the quantity of atoms or molecules in a gram-molecular weight respectively, equating to 6.02214×10^{23} atoms or molecules/mole (see **AVOGADRO'S CONSTANT**).

Azimuthal (orbital angular) momentum quantum number (ℓ)

[atomic, high-energy, nuclear, quantum, solid-state] QUANTUM NUMBER introduced to define the additional DEGREES OF FREEDOM with respect to the nuclear and electron MOTION for the ATOM next to the principle quantum number (n). The azimuthal momentum quantum number or orbital angular momentum quantum number describes the degree of rotation and associated "FINE-STRUCTURE" splitting resulting from PRECESSION. The angular momentum associated with the wavemechanics of an electron in orbit is $L = \hbar\sqrt{\ell(\ell+1)}$, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, and $\ell = 0, 1, 2, \dots, n-1$. Electron transitions are governed by the PAULI EXCLUSION PRINCIPLE (see [Figure A.111](#)).

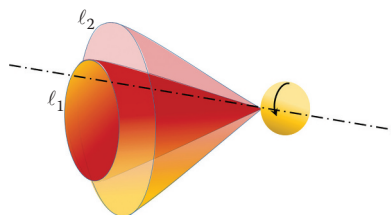


Figure A.111 Representation of the angular (azimuthal) momentum quantum number associated with the energy state of the atomic electron spin.



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Bacher, Robert Fox (1905–2004)

[nuclear] A physicist from the United States. One of the principal scientists on the MANHATTAN PROJECT. The work of Robert Bacher provided significant insight into the structure of the atomic NUCLEUS (see [Figure B.1](#)).



Figure B.1 Robert Fox Bacher (1905–2004). (Courtesy of Los Alamos National Laboratory, Los Alamos, New Mexico.)

Backscatter

[acoustics, optics] Optical and/or pressure waves that are reemitted from within a medium that thus carry information about the object the waves interacted with. In OPTICS, the angular spread of the backscattered light will provide details about the size of the SCATTERING cross-sectional area, described

by JOHN WILLIAM STRUT, THE 3RD BARON RAYLEIGH (1842–1919) and GUSTAV ADOLF FEODOR WILHELM LUDWIG MIE (1869–1957). In ACOUSTICS, the resonant remittance of SOUND waves provides details about the elastic modulus of the region and the discontinuity with the surrounding volume (see [Figure B.2](#)).

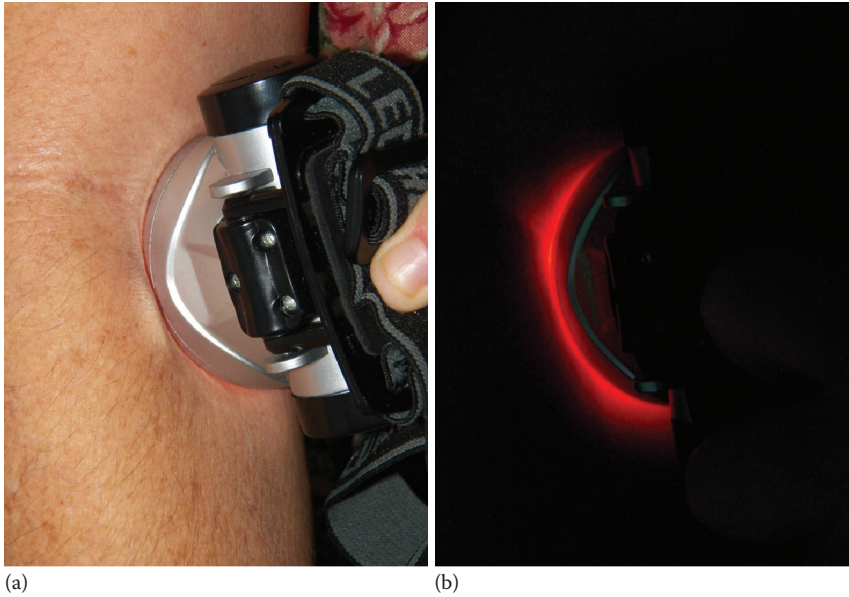


Figure B.2 (a) Image representing the concept of backscatter. (b) The arm with little pigment scatters the incident light back, primarily the red light from the white light source pressed up against the skin shown in (a).

Bacon, Francis, Sir (1561–1626)

[general] A scientist and philosopher from Great Britain (later known as Lord Verulam). The work of Sir Bacon describes the equivalence of MOTION and heat; following in the footsteps of PLATO (427–347 BC), he defined the equivalence of motion (kinetic ENERGY) and thermal phenomena. Additional work by Sir Bacon provided insight into the charges released when certain LATTICE structures are broken, and he described the sparks generated when sugar crystals are broken (see [Figure B.3](#)).



Figure B.3 Sir Francis Bacon (1561–1626), engraved by James Posselwhite.

Bacon, Roger (1214–1294)

[general] A scientist and philosopher from Great Britain, as well as Franciscan friar. The work of Roger Bacon with respect to OPTICS, corrective VISION more precise, was published in the *Opus Majus* in 1267.

Bacteriorhodopsin

[biomedical, chemical, thermodynamics] A transmembrane protein used in ENERGY conversion and ACTIVE TRANSPORT for harvesting light energy and converting it to electrostatic energy in the form of PROTON transport (PTR: $\frac{1}{2}H^+$) to be transported out of the CELL for energy delivery elsewhere. Bacteriorhodopsin is part of certain rod-CELL MEMBRANE structures, pertaining to intensity VISION (not necessarily for COLOR [cone] vision). The light-induced proton transport against the proton gradient is a significant feature in bioenergetics. Bacteriorhodopsin is a CHROMOPHORE that converts light into electrochemical energy through a protonated Schiff base within a time frame in the order of 2 femtoseconds. The chemical process following the light conversion results in chemical conversion to bathorhodopsin after 2000 fs = 2 ps, initiating a change in MEMBRANE permeability leading up to cellular DEPOLARIZATION. Only several photons acquired simultaneously are required to produce a full depolarization, resulting in the electrical stimulus conveying the observation of several photons to the brain. On a local cellular membrane level, the effects of the interaction of a single photon can be verified. The chemical process involves the isomerization of carbon–carbon double bond (C-11) with a high energy GROUND STATE which is sterically strained. In the isomerization, the order/sequence of certain atomic structures with the large molecule is rearranged, forming another molecule with the same atoms in total. Additional chemical processes in the integral process of light reaction are the electron coupled and PROTON transfer in complex IV of cytochrome-*c*-oxidase (electron transport chain). The energetic process of proton transfer can be described through a SOLUTION of the SCHRÖDINGER WAVE EQUATION for the VALENCE bond RESONANCE structures, with WAVE functions representing the protonated and deprotonated sets of acceptors with valence bond resonance: Ψ_1 representing retinal (Schiff base) amino ACID Asp85 and Ψ_2 representing retinal amino acid Asp-H. The wave functions for the chemical structures in bacteriorhodopsin are defined through: $\Psi_1: R_1 \equiv C(H) = N^+(R_2)H - A_1$, A_1 representing the acceptor (Asp85) and R_i the rest-terms of the large molecule (MOLECULAR WEIGHT of bacteriorhodopsin $35,200 \pm 1,200$), N stands for nitrogen, C stands for carbon, and H stands for hydrogen; $\Psi_2: R_3 \equiv C(H) = N^+(R_4)H - A_2$, A_2 : Asp-H. The respective diabatic SURFACE ENERGY states for the two conditions and photochemical interactions and diabatic states associated with the two wave functions (1 and 2) are $\bar{\epsilon}_1 = \epsilon_{\text{QCFF/PI}}(\text{SBH}^+) + \epsilon'_{\text{Asp85}} + \epsilon_{\text{SS}}^{(1)} + \epsilon_{\text{SS}}^{(1)} + \epsilon_{\text{ss}} + \alpha^{(1)}$ and $\bar{\epsilon}_2 = \epsilon_{\text{QCFF/PI}}(\text{SB}) + \epsilon'_{\text{AspH85}} + \epsilon_{\text{SS}}^{(2)} + \epsilon_{\text{SS}}^{(2)} + \epsilon_{\text{ss}} + \alpha^{(2)}$, respectively; the surface energy of the chromophore is given by $\epsilon_{\text{QCFF/PI}}$, which incorporates the potential from the solvent/protein system (QUANTUM mechanical consistent force field method for Pi-electron systems [QCFF/PI]) for the Schiff base, ϵ' is an empirical electron valence bond (EVB) description of Asp85 or AspH85, ϵ_{SS} is the interaction between the classical EVB and π -electron systems, and $\epsilon_{\text{SS}}^{(i)}$ represents the interaction between the SOLUTE (S) and the SOLVENT (s) in the given state, while $\alpha^{(i)}$ defines the “gas-phase shift,” incorporating the covalent influences of the water environment on the proton transfer. The classical

EVB and π -electron systems can be treated as regular EVB because the steric interactions between the two fragments and the classical electrostatic interactions can be considered under classical mechanical terms instead of QUANTUM MECHANICS. The Franck–Condon factor (FCF) for the process between the two states is given as $\text{FCF} = |\int_{-\infty}^{\infty} \Psi_n^{1*}(x) \Psi_m^2(x) dx|$. Incorporating the GROUND STATE (E_g) into the energy balance is accomplished through the use of the off-diagonal coupling ELEMENT tying the wave functions H^{12} in the form: $E_g = (1/2) \{ (\epsilon_1 + \epsilon_2) - [(\epsilon_1 - \epsilon_2)^2 + 4(H^{12})^2]^{1/2} \}$. The depolarization is fueled by the proton motive force (PMH(Δp)); compare to electromotive force), consisting of a CHEMICAL GRADIENT (ΔpH) and a pure charge gradient ($\Delta\Psi$) expressed as $\text{PMH}(\Delta p_{\text{proton}}) = \Delta pH + \Delta\Psi$ (see Figure B.4).

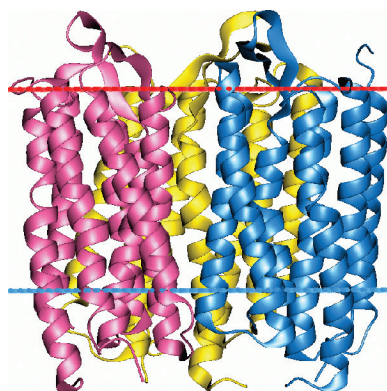


Figure B.4 Graphical representation of bacteriorhodopsin as part of the membrane proton-pump mechanism, the red line illustrates the external side of the bilipid membrane. (Courtesy of Andrei Lomize.)

Baffled piston

[acoustics, imaging] Acoustical screening for vibrating piston to steer the acoustic profile, focus as well. The baffle provides a filtering mechanism to counteract the out-of-phase waves originating from other parts in the moving system, for instance, the backside of the piston. The backside of the piston has an extended travel DISTANCE for the pressure WAVE and is hence not necessarily in PHASE with the pressure wave emerging at the front. The baffled piston provides the mechanism used to acquire SIGNAL used for velocity-based near-field acoustic holographic imaging. In the holographic imaging process, the pressure ($P(\vec{r}, t)$) wave obeys the homogeneous WAVE EQUATION in three-dimensional space $\nabla^2 P(\vec{r}, t) - (1/v_s^2)(\partial^2/\partial t^2)P(\vec{r}, t)$, with v_s the speed of SOUND (see Figure B.5).

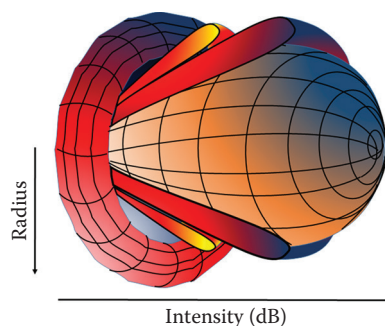


Figure B.5 Power profile of baffled piston, used, for instance, in naval sonography.

Bainbridge, Kenneth Tompkins (1904–1996)

[atomic, nuclear] A physicist from the United States who was instrumental in the development process and theoretical analysis of the CYCLOTRON. Kenneth Bainbridge's research on the mass differences between isotopes provides the evidence to support the theoretical concept of the mass–energy equivalence as proposed by ALBERT EINSTEIN (1879–1955) (see [Figure B.6](#)).



Figure B.6 Kenneth Tompkins Bainbridge (1904–1996). (Courtesy of Los Alamos National Laboratory, Los Alamos, New Mexico.)

Bakelite®

[biomedical, solid-state] Polyoxybenzylmethyleneglycolanhydride, one of the first synthetic PLASTICS. Bakelite is strong and temperature resistant to high temperatures. The chemical basis is thermosetting phenol formaldehyde resin. Bakelite is formed resulting from an elimination reaction of formaldehyde with phenol, combined with strengtheners such as wood pulp or CELLULOSE. It is a composite material designed in 1907 and commercially introduced in 1939. Due to its mechanical, thermal, and chemical properties, bakelite is used in various consumer items (e.g., rotor for distributor in car), poker chips, billiard balls, and chess pieces, as well as in medical devices in its early days, and still is to a lesser degree. The name was derived from the Belgian inventor LEO HENRICUS ARTHUR BAEKELAND (1863–1944) (see [Figure B.7](#)).



Figure B.7 Picture of a cook pot with bakelite handle.

Ballistic motion

[general] The trajectory associated with projectiles that are ejected under explosive force (e.g., bullet and metallic glowing cinders produced under welding) or under mechanical impulse (e.g., baseball). The trajectory of the ballistic PROJECTILE is a product of the resultant of the forces acting on the object. GRAVITY being the constant force acting in vertical direction, whereas only a force acts on release in a generalized direction, based on the planned target range. The ballistic projectile will provide a parabolic track that obeys the path outlined by the initial escape VELOCITY ($\vec{v}_i$, with horizontal projection $v_{ix} = v_i \cos \theta$ [neglecting fluid resistance] and vertical projection $v_{iy} = v_i \sin \theta$) providing the horizontal displacement $s_x = v_{ix}t$ as a function of time t , and the vertical DISTANCE $s_y = v_{iy}t + (1/2)gt^2$ with a maximum height when released in upward direction, for example, cork form champagne bottle (g is the GRAVITATIONAL ACCELERATION); the time is derived from the duration in which the vertical MOTION is suspended (hits the GROUND/target) (see Figure B.8).



Figure B.8 Ballistic motion of a cannonball.

Balmer, Johann Jakob (1825–1898)

[atomic, computational, general, nuclear, solid-state] A computational physicist and mathematician from Switzerland. In 1885, Johann Balmer defined hydrogen excitation spectra by the BALMER SERIES, where the transition FREQUENCY (ν) spectrum is defined as $\nu = cR \left[\left(\frac{1}{2^2} \right) + \left(\frac{1}{n^2} \right) \right]$, where $R = 10,967,758 \text{ m}^{-1}$ is the RYDBERG CONSTANT, $c = 299,792,458 \text{ m/s}$ is the speed of light, and $n = 3, 4, 5, \dots$ is an integer depicting the excitation levels. The balmer series emission lines (i.e., ATOMIC LINE SPECTRA) are all in the visible spectrum (see Figure B.9).



Figure B.9 Johann Jakob Balmer (1825–1898).

Balmer series

[atomic, general, nuclear] Hydrogen excitation spectra are described by JOHANN JAKOB BALMER (1825–1898) in 1885. The electron transitions within the HYDROGEN ATOM generate a set of discrete emission wavelengths with FREQUENCY (ν) spectrum defined as $\nu = cR \left[\left(\frac{1}{2^2} \right) + \left(\frac{1}{n^2} \right) \right]$, where $R = 10,967,758 \text{ m}^{-1}$ is the RYDBERG CONSTANT, $c = 299,792,458 \text{ m/s}$ is the speed of light, and $n = 3, 4, 5, \dots$ is an integer depicting the excitation levels. The Balmer series emission lines (i.e., ATOMIC LINE SPECTRA) are all in the visible spectrum, also known as Balmer formula (see Figure B.10).



Figure B.10 Balmer lines in the visible spectrum representative of hydrogen gas emission. (Courtesy of Jan Homann.)

Balmer thermometer

[astronomy/astrophysics] An indicator of stellar ACTIVITY by means of the ENERGY spectrum expressed by the number (N) of neutral H atoms in the excited ($n=2$) state available to produce Balmer lines. This THERMOMETER expresses the stellar temperature in KELVIN (see Figure B.11).

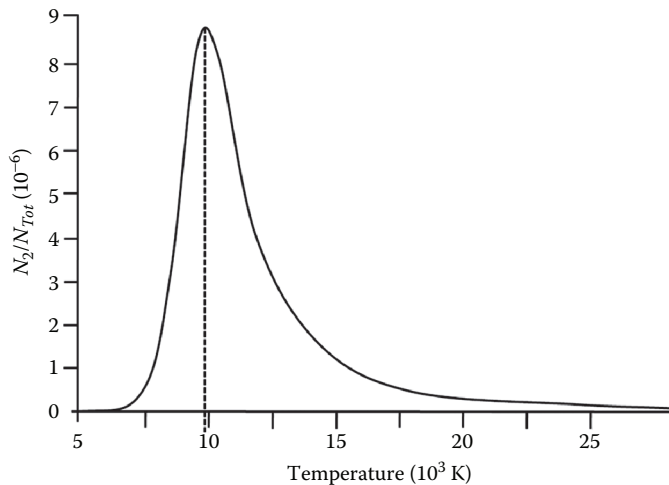


Figure B.11 Balmer thermometer emission energy spectrum.

Bar magnet

[general] It is the simplest construction for a MAGNET and has a well-defined NORTH and south pole on the opposite sides of the long section of the bar. The MAGNETIC FIELD lines curve around the long side of the bar in all directions forming a set of concentric elongated doughnuts in outline. When placed underneath a paper sheath, the cross-sectional outline of the field lines will become evident. Note that the magnetic field lines always form closed loops (see [Figure B.12](#)).



Figure B.12 Bar magnet with paperclips attached on the north- and south pole, connecting the magnetic field loop.

Bardeen, John (1908–1991)

[electronics, solid-state] A physicist from the United States, known for his pioneering efforts in semiconductor PHYSICS next to his work in SUPERCONDUCTIVITY. John Bardeen received a Nobel Prize in Physics in 1956 for his work on transistors, shared with WALTER HOUSER BRATTAIN (1902–1987) and WILLIAM BRADFORD SHOCKLEY (1910–1989), and he received another Nobel Prize in Physics in 1972 regarding superconductivity, shared with LEON NEIL COOPER (1930–) and JOHN ROBERT SCHRIEFFER (1931–). In 1947, Bardeen discovered the transistor function while working at the Bell laboratories (see [Figure B.13](#)).



Figure B.13 John Bardeen (1908–1991). (Courtesy of the Nobel Prize files.)

Barkla, Charles Glover (1877–1944)

[atomic, nuclear] A physicist from Great Britain. In 1911, Barkla revealed his discovery of the emission lines in the X-RAY spectrum resulting from ATOMIC EMISSION transitions, which are sharp lines. These lines are superimposed on the broad BREMSSTRAHLUNG spectrum. Charles Barkla received the Nobel Prize in Physics for his work in 1917. Charles Barkla also discovered the fact that X-ray had POLARIZATION, similar to ordinary visible light, allowing the extrapolation of the ELECTROMAGNETIC SPECTRUM. The work of Barkla also illustrated the correlation between the characteristic LINE SPECTRUM and the RADIATION consisting of PARTICLE emission during Röntgen radiation (see Figure B.14).



Figure B.14 Charles Glover Barkla (1877–1944). (Courtesy Library of Congress, George Grantham Bain Collection, Washington, DC.)

Barn (the unit)

[atomic, nuclear] A cross-sectional unit in nuclear dimensions, $1 \text{ barn} = 10^{-28} \text{ m}^2$. The unit expresses the PROBABILITY of a specific nuclear reaction taking place in terms of cross-sectional area.

Baroclinic waves

[fluid dynamics, geophysics] Atmospheric waves that migrate and incorporate horizontal thermal gradients and variability of FLOW as a function of altitude, essentially caused by the changing CORIOLIS FORCE with altitude. In order to account for variability in properties with altitude, a new reference frame is introduced to allow for the use of standard WAVE EQUATION. The “virtual” altitude (ζ^*) is corrected by means of PRESSURE (P , against a reference P_0) and temperature (T) as $\zeta^* = H_{00} \ln(P_0/P)$, where $H_{00} = RT_{00}/g$ is the equivalent height of the column, $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant, and g is the GRAVITATIONAL ACCELERATION. The vertical velocity for atmospheric flow is defined as $w^* = D\zeta^*/Dt = -(H_{00}/P)\varpi_T$, where ϖ_T is the vorticity and $D/Dt = [(\partial/\partial t) + (\vec{v} \cdot \nabla)]$, $\vec{v}$ is the velocity vector. For the equivalent VELOCITY POTENTIAL ($\Psi_v^* = \Phi_v/f_{C0}$, Φ_v the velocity potential), the equation of MOTION is now defined as $[(\partial/\partial t) + u_g(\partial/\partial x) + v_g(\partial/\partial y)]\nabla^2\Psi_v^* + \beta_C(\partial/\partial x)\Psi_v^* = f_{C0}[\exp(\zeta^*/H_{00})](\partial/\partial \zeta^*)\{w^*\exp[-(\zeta^*/H_{00})]\}$, where f_{C0} is the geostrophic vorticity, and β_C is the Coriolis parameter, with the longitude and LATITUDE velocity components, respectively, $v_g = (\partial/\partial x)\Psi_v^*$ and $u_g = -(\partial/\partial y)\Psi_v^*$. In thermodynamic perspective, the temperature (T) effects are represented as $(\partial/\partial \zeta^*)\Psi_v^* = RT/f_{C0}H_{00}$, where H_{00} is the equivalent “pressure” height. The generalized solutions are provided in the format $\Psi_v^* = [\text{Const} \times e^{-(\zeta^*/2H_{00})} e^{i(\omega_0 t + k_{xx}x + k_{yy}y + k_{\zeta\zeta^*}\zeta^*)}]$, where intrinsic angular frequency $\omega_i = 2\pi\nu_i$ (ν_i is the intrinsic frequency), k_{xx} is the wave number for the

longitudinal direction, k_y is the wave number as a function of latitude, with boundary condition $\kappa_z^2 = v_{BV}^2 / f_{C0}^2 \left[\beta_C / (\mu_0 + (\omega_i / k_z)) - (k_x^2 + k_y^2) \right] - (1/4 H_{00}^2)$, where $v_{BV} = \sqrt{[(g/\theta_\rho)(\partial\theta_\rho/\partial z^*)]}$ is the BRUNT-VÄISÄLÄ BUOYANCY FREQUENCY, θ_ρ is the local temperature, as a function of DENSITY (ρ). The baroclinic wave describes the situations pertaining to conditions that do not apply to BAROTROPIC WAVES, also known as baroclinic Rossby waves (*also see* BAROTROPIC WAVE *and* LAMB WAVE) (see Figure B.15).

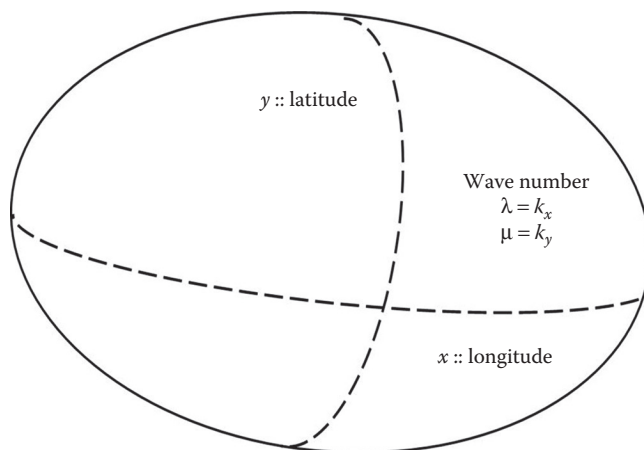


Figure B.15 Reference for the nomenclature used in the baroclinic and barotropic wave pattern definition.

Barometer

[energy, fluid dynamics, general, geophysics] A device used to measure the ATMOSPHERIC PRESSURE. The first barometer was constructed by EVANGELISTA TORRICELLI (1608–1647) in 1643. The barometer uses the principle of COMMUNICATING VESSELS to measure the height of a column of mercury with density ρ_{Hg} to match the height of a column of AIR with density ρ_{air} , the air density declines with altitude and hence the MEASUREMENT performs a virtual integration (see Figure B.16).



Figure B.16 Picture of barometer indicating the pressure and the anticipated weather conditions.

Barometric law

[fluid dynamics, geophysics] See LAW OF THE ATMOSPHERES.

Barotropic waves

[fluid dynamics, geophysics] Large-scale atmospheric WAVE patterns that are generated as a result of the changing CORIOLIS FORCE with altitude. In a barotropic Rossby wave, the total VORTICITY (ϖ_T) is conserved: the sum of the geostrophic vorticity (ϖ_g) and the MAGNITUDE contribution by the earth's vorticity ($f_C = f_{C0} + \beta_C y$; β_C is known as the Coriolis parameter). Barotropic waves have an essential influence on the midlatitude weather development by means of forming the large-scale CIRCULATION based on its crests and troughs. The changing Coriolis parameter as a function of altitude (y) ($\beta_C = \partial f_C / \partial y$) creates a restoring force in the horizontal direction, with ensuing horizontal oscillations in pressure fronts generating the barotropic waves. The WAVE EQUATION provides the DISPERSION for the wave with wave number $k = 2\pi/\lambda$, where λ is the wavelength, and the pattern has an intrinsic angular frequency $\omega_i = 2\pi\nu_i$ (ν_i is the intrinsic frequency), defining the PHASE VELOCITY as a function of LATITUDE (ℓ) as $\omega_i/k = \beta_C / [k^2 + \ell^2 + (f_{C0}^2/gH)]$, where g is the GRAVITATIONAL ACCELERATION and H is the height of the atmospheric column. For stationary waves, the wavelength is derived to be represented as $\lambda_{Bs} = 2\pi\sqrt{(\bar{u}/\beta_C)}$, where $\bar{u}$ is the migration/DRIFT VELOCITY perturbation; for instance, at latitude 50°N with $\bar{u} = 10\text{ m/s}$, this provides $\lambda_{Bs} = 5179\text{ km}$. Waves that have a shorter WAVELENGTH ($\lambda < \lambda_{Bs}$) will travel west to east, and at greater wavelengths ($\lambda > \lambda_{Bs}$), they will migrate east to west. As a reference, nonstationary barotropic waves at midlatitude will travel eastward at a rate of approximately $6^\circ\text{longitude/day}$. The barotropic wave pattern is indicated on global weather maps represented by the 50 kPa pressure surface (which equates to the geopotential), with wavelength stretching 1000 km or more. Expanding the wave equation to three dimensions yields the influence of a stratified ATMOSPHERE and wave propagation in the vertical direction $\omega_i/k = -\beta_C / [k^2 + \ell^2 + (f_{C0}^2/\nu_{BV}^2)(\partial_m^2 + C_{\text{Eckart}}^2)]$, where ∂_m represents the dampening coefficient, ν_{BV} is the BRUNT-VÄISÄLÄ BUOYANCY FREQUENCY, $C_{\text{Eckart}} = [1/2\rho(z)][\partial\rho(z)/\partial z] + g/\nu_s^2$ defines the Eckart coefficient, a scale of the ratio of the moment of INERTIA for the different wave aspects; angular—translational (a parameter carried over from QUANTUM mechanical analysis with respect to molecular interaction) ($\rho(x, y, z)$ the perturbation to the density as a function of location and height, ν_s is the speed of SOUND). Barotropic waves are often forced by the local topography, Rocky Mountains, Andes Mountains, Himalayas, and so on. Generally, barotropic wave theory assumes that there is no vertical velocity for the wave (the AIR is moving), a “standing wave” approach. Including vertical propagation is discussed under BAROCLINIC WAVES, also known as barotropic Rossby wave or Rossby wave. The name CARL-GUSTAF ARVID ROSSBY (1898–1957) is associated with the atmospheric waves due to the initial discovery and theoretical description by this Swedish meteorologist and scientist in 1919. A similar process is found in the oceanic fluctuations where the FLOW velocity at great depth is in the order of 2 m/day, and a time constant is in the order of years (also see BAROCLINIC WAVES) (see Figure B.17).

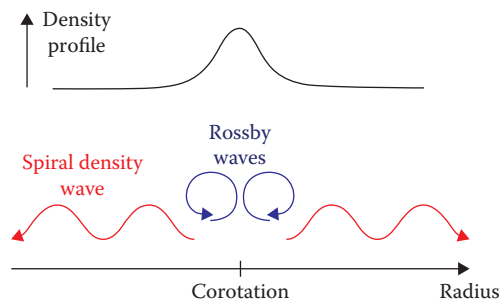


Figure B.17 Barotropic Rossby wave in atmospheric jet-stream evolution.

Barrier

[nuclear] *See* COULOMB BARRIER, FISSION BARRIER, *and* POTENTIAL BARRIER.

Bartlett, James Holley (1904–2000)

[chemical, dynamics, general, nuclear] A scientist from the United States who contributed to the description and definition of the DONNAN EQUILIBRIUM.

Baryon

[atomic, general, quantum] Heavy subclass of the PARTICLE group HADRON, examples are NEUTRON and protons. Baryons can be “strange” and “charmed.” Baryons obey FERMI–DIRAC STATISTICS and have half-integral SPIN, also known as FERMIONS. They are the complementary particles of MESONS, which obey BOSE–EINSTEIN STATISTICS and have zero or integral spin, also known as BOSONS. Masses of the known baryons as well as mesons range from one-seventh of that of the PROTON for the pi MESON, extending 10 times the proton mass. Baryons are subject to the STRONG NUCLEAR FORCE. The known baryons are $p, n, \Delta, \Lambda, \Sigma$. In 1964, both MURRAY GELL-MANN (1929–) and GEORGE ZWEIG (1937–) provided evidence that baryons (as well as the other hadron group: mesons) are not primary ELEMENTARY PARTICLES. Baryons are composed of quarks, the smallest elementary particle currently known and verified.

Baryon number

[atomic, general, quantum] In order to satisfy the conservation principle for BARYONS, the BARYON NUMBER $B = 1$ was introduced with respect to the antibaryon ($B = -1$), whereas nonbaryons have $B = 0$.

Basal metabolism

[biomedical, thermodynamics] The average ENERGY consumption rate for the HUMAN BODY at rest (maintaining equilibrium, constant temperature, etc.), keep in mind that the metabolic rate is a function of height, weight, AGE, and current and prior ACTIVITY: 72 calories/h = 301.45 J/h. At this rate, the daily recommended consumption comes to approximately 2000 calories, as listed as a reference on several food packaging with regard to nutritional guidelines.

Basic forces of nature

[energy, general, nuclear, quantum, thermodynamics] Force can be classified into four types—STRONG NUCLEAR FORCE, weak nuclear force, electromagnetic force (its subdivision is ELECTROWEAK FORCE), and gravitational force.

Basilar membrane

[acoustics, biomedical, computational, general] SENSORY structure in the COCHLEA of the EAR that converts a mechanical VIBRATION to ELECTRONIC impulses. The conversion is performed by a long stretch of hairs lining the length of the cochlea construction, resembling a snail shell. The hairs are part of the ORGAN OF CORTI.

When the hair bends and applies shear strain to the MEMBRANE, it generates an ACTION POTENTIAL as described in the entry for the ORGAN OF CORTI (see Figure B.18).

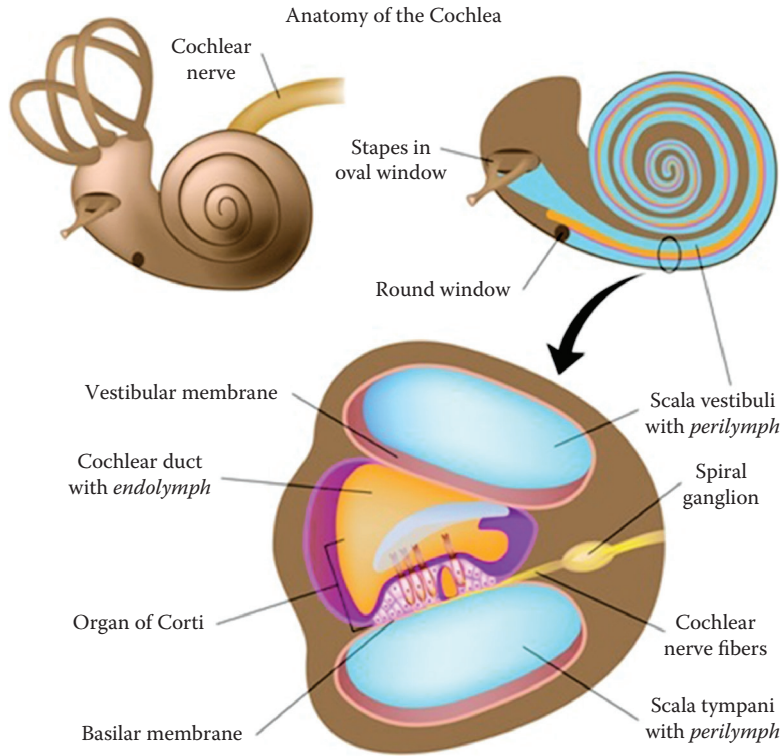


Figure B.18 Basilar membrane in the cochlea of the ear.

Bat

[acoustics, biomedical] The only mammal capable of sustained flight, with the use of webbed wings. The WING of the bat is remarkably distinguished from those of birds and pterosaurs, both are not mammals. Bats generally rely on acoustic TELEMETRY for hunting and flight guidance. Bats are of the biological order Chiroptera, with the following Greek reference, contraction of $\chi\epsilon\iota\rho$ (phonetic: cheir), which translates roughly as hand, and $\pi\tau\epsilon\rho\omega\nu$ (phonetic: pteron), meaning wing. Certain bats use ACOUSTIC probing at frequencies (ν) reaching in excess of 200 kHz. The guidance by ACOUSTICS is also used by submarines. Based on general sensing constraints, the RESOLUTION associated with wavelength-based detection cannot generally exceed half the shortest WAVELENGTH ($\lambda_{\min}$), which at 200 kHz equates to $\text{Res} = (1/2)\lambda_{\min} = (1/2)(v_{\text{sound}} / \nu) = (1/2)(340.29\text{ m/s} / 2 \times 10^5\text{ s}^{-1}) = (1/2)1.7015 \times 10^{-3}\text{ m} \approx 850\text{ }\mu\text{m}$, where $v_{\text{sound}} = 340.29\text{ m/s}$ in AIR at standard temperature and pressure. In comparison, human VISION is limited by both the RAYLEIGH CRITERION and the density of RODS and CONES in the FOVEA. On average, the eyes can distinguish two point sources with angular resolution of $0.3\text{ arc min} = 0.0000872\text{ rad}$ apart, resulting in a

spatial resolution at the center wavelength 550 nm applying a focal length of 22 mm to an object placed in the NEAR POINT of the HUMAN EYE (0.25 m) yielding approximately 88.65 μm resolution on average. Alternatively, the bat is used to strike a ball in the sports baseball and cricket (see [Figure B.19](#)).



Figure B.19 Picture of a representative bat.

Battery

[energy, general] A reversible electrical ENERGY storage device. Electrical energy can be stored primarily by chemical means, which can be released under reversed conditions. When applying an electrical current to the battery, the internal structure and composition converts the electrical energy into a form of energy that will hold the potential energy for a finite lifetime, and the process can be reversed to release an electrical current for later use. Certain batteries hold only potential electrical energy based on the production process and will only deliver current under a fixed electrical voltage. For instance, a lead battery for a car operates on the following principle: $\text{PbO}_2 + 2\text{H}_2\text{SO}_4 + \text{Pb} \leftrightarrow \text{PbSO}_4 + 2\text{H}_2\text{O} + \text{PbSO}_4$, where the ANODE is made from PbO_2 , while the CATHODE is made from porous lead (Pb), with WATER (H_2O) and sulfuric ACID (H_2SO_4) as catalyst and SOLUTE. In the lead battery, the electric potential (ϵ_{emf} or V_{EMF}) primarily depends on the sulfuric acid concentration. The electrical potential of the battery can be described by a function derived from the GIBBS FREE ENERGY as $\Delta\epsilon_{\text{emf}} = \Delta\epsilon_{\text{emf}}^0 - (RT/nF_{\text{Helmholtz}}) \ln Q_r$, also known as the NERNST EQUATION or NERNST POTENTIAL, where ϵ_{emf} is the electromotive TRANSMEMBRANE POTENTIAL, $R = 8.314462175 \text{ J/Kmol}$ is the universal GAS constant, and T is the temperature. This equation also provides the potential difference generated in a galvanic CELL as a function of the ION concentrations in both compartments during equilibrium. In this equation, Q_r states the ratio of the respective compartmental ionic concentrations (see [Figure B.20](#)).

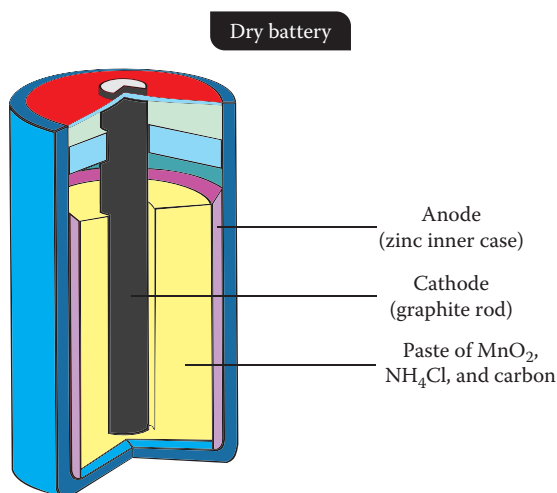


Figure B.20 Picture of a C-cell battery cut open, revealing a graphite core electrode.

Bayes, Thomas (1701–1761)

[biomedical, computational] A statistician and mathematician from Great Britain. Bayes is most known for his posthumously published work on “inverse probability,” used to predict the verification of a phenomenon, known as the BAYES’ THEOREM.

Bayes’ theorem

[biomedical, computational] A PROBABILITY theory pertaining to the occurrence of an event (or data point) (E_{data}) with respect to a scientific hypothesis ($P(H_i)$) related to another event (H_i). The principle of combining the recently acquired data with experimental observations recorded previously was introduced in the mid-eighteenth century by THOMAS BAYES (1701–1761) to provide a mechanism of verification. The theorem is sometimes used to validate the PERCEPTION of an observation and hence verify the assumptions made that define a condition. This process can also be applied prior to performing the experiment. The BAYES’ THEOREM is also used in MEDICINE to ascertain the probability of the presence of a medical condition based on laboratory findings and patient examinations. In medicine, the derivation is not necessarily based on computational processes, rather on likelihood from documented and personal experiences. Many events/observations with associated hypothesis and data points involved in a single phenomenon will converge to yield the probability of the occurrence of a specific phenomenon. Mathematically, this is defined as the probability of the correctness of the hypothesis under the observation of specific experimental data $P(H_i|E_{\text{data}}) = P(H_i)P(E_{\text{data}}|H_i) / \sum_i P(H_i)P(E_{\text{data}}|H_i)$, where $P(E_{\text{data}}|H_i)$ represents the probability of obtaining realistic observations under the assumption H_i .

Bayesian statistics

[biomedical, computational] A prediction and verification mechanism of action based on the BAYES’ THEOREM.

Bazin equation, open channel

[fluid dynamics] Considering the free FLOW in a water channel, defined as having one exposed surface to open AIR, there are several factors to consider. Water channels can be traced back to at least 300 BC with respect to the Roman aqueducts, stretching 16.5 km. Water channels are frequently deep with rough WALL and high flow rate and hence a high REYNOLDS NUMBER that ensures turbulent flow. Under the high flow rate and rough surface on the walls of the channel, the ROUGHNESS ($\alpha_{\text{roughness}}$, found in tables; shaved wood surface: $\alpha_{\text{roughness}} = 0.06$, concrete: $\alpha_{\text{roughness}} = 1.30$, canal bed with grass and rocks: $\alpha_{\text{roughness}} = 2$) becomes the determining factor in the boundary flow. The “wetted perimeter” (s_w) of the channel is the contiguous length stretching from one edge across the bottom surface up to the opposing edge at the free surface. Consider that the channel is uniform over its length ℓ , with shear stress at the wall σ_s , the FRICTION must balance the gravitationally induced flow (under incline ANGLE θ), for LIQUID with density ρ flowing through a CROSS SECTION A , since the liquid is not accelerating, as $\rho g \ell \sin \theta = \sigma_s s \ell$. The shear stress can be approximated as a function of the flow velocity v as $\sigma_s = f_f \rho (v^2/2)$, where f_f is the frictional coefficient. This allows the flow velocity to be written as $v = \sqrt{2g \sin \theta / f_f} = c_f \sqrt{(d_b \sin \theta)}$, since the angle is small $\tan \theta \cong \sin \theta$. The mean hydraulic depth can be defined as $d_b = A/s_w$. In channel flow, the flow velocity coefficient (c_f) is expressed by the Bazin equation $c_f = 87 / [1 + (\alpha_{\text{roughness}} / \sqrt{d_b})]$ (also see CHEZY EQUATION).

Beam forming

[acoustics, optics] A linear parameter estimation process used to define the incident **ANGLE** of a ray/beam with the specific associated distribution of **MAGNITUDE** as a function of angle and location. The beam-forming process is designed to represent a profile that will provide the optimal configuration for specific **RESOLUTION** imaging applications. In certain cases, the beam profile may need to be altered in the process of **SIGNAL** acquisition. In **OPTICS**, a laser beam may be formed to produce a specific spot shaped by means of lenses. One specific optical beam-forming mechanism is **LENS-AXICON FOCUSING**. In **ACOUSTICS**, the use of certain arrangements of sources (**PHASED ARRAY**) or single source with **ORIFICE** (damped piston) can provide a specific emission profile in angular distribution and in spatial outline.

Bearden, Joyce Alvin (1903–1986)

[atomic, nuclear] A physicist from the United States who worked on the identification of atomic structures by means of **X-RAY** probing. Bearden listed the characteristic lines for a range of **ELEMENTS**. He was a student of **ARTHUR HOLLY COMPTON** (1892–1962).

Beat frequency

[acoustics, general, imaging, mechanics, optics] The frequency difference between two frequencies that are closely separated (*see* **BEATS**).

Beats

[acoustics, general, imaging, mechanics, optics] The superposition of two waves that are slightly off on the **WAVELENGTH** (λ) produces an **INTERFERENCE** that has an optimum at the difference between the two wavelengths. The **BEAT FREQUENCY** ($\nu = \omega/2\pi$) is observed at the low frequency, fading in and out with the period of the beat frequency next to the base frequencies. The superposition principle provides the mechanism to describe the effect as $\sin(\omega_1 t) + \sin(\omega_2 t) = 2 \sin\left[\frac{(\omega_1 + \omega_2)t}{2}\right] \cos\left[\frac{(\omega_1 - \omega_2)t}{2}\right]$, creating the mean angular frequency $\omega_1 t + \omega_2 t/2$, at small difference, to be **AMPLITUDE** modulated at angular frequency $\Delta\omega = (\omega_1 - \omega_2)$. In case the two wavelengths are separated beyond a certain threshold (greater than 0.01% for **ACOUSTICS** and greater than 0.001% for **ELECTROMAGNETIC RADIATION**), the two waves are perceived as separate waves. In acoustics, this can, for instance, be heard for two diesel trains running at almost equal revolutions per minute, but at less than a few Hz off (~at a fraction of a Hz off) to **SOUND** as the mean frequency for the two trains becoming louder and fading out at the beat frequency (*see* [Figure B.21](#)).

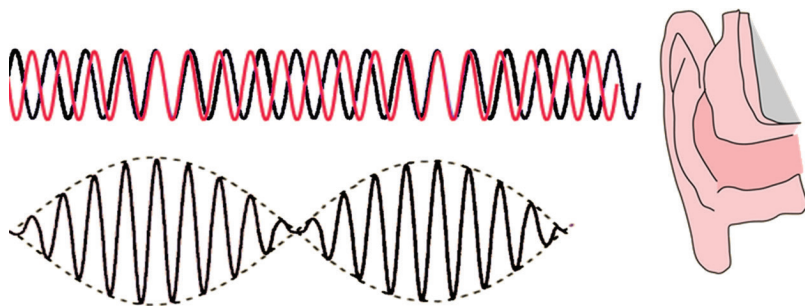


Figure B.21 Graphical illustration of the beat frequency concept.

Beattie–Bridgeman equation of state

[thermodynamics] A thermodynamic relation between PRESSURE (P), VOLUME (V), and TEMPERATURE (T) as a refinement to the VAN DER WAALS EQUATION. The Beattie–Bridgeman equation of state was introduced by James Alexander Beattie (1895–1981) and OSCAR Cleon Bridgeman (1897–1967) in 1928. The Beattie–Bridgeman equation of state has the following format: $P = (RT/V) \left[1 - (c'/VT^3) \right] \left\{ 1 + (B_0/V) [1 - (b'/V)] \right\} - \left\{ (A_0/V^2) [1 - (b'/V)] \right\}$, where A_0 , B_0 , and a' , b' , and c' are constants that represent the specific properties of the substance and are listed in look-up tables for the respective boundary conditions and gasses in question.

Becquerel, Antoine Henri (1852–1908)

[atomic, general, nuclear] A scientist from France dedicated to FLUORESCENCE. His contributions to the definition of nuclear RADIATION and RADIOACTIVITY were helpful after the discovery of X-RAY radiation by WILHELM CONRAD RÖNTGEN (1845–1923) (see [Figure B.22](#)).

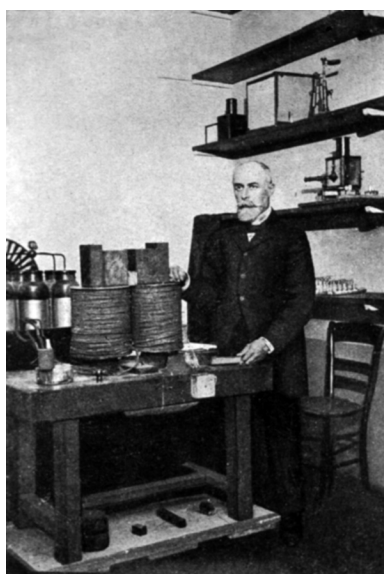


Figure B.22 Antoine Henri Becquerel (1852–1908) in the laboratory performing experiments with magnets.

Becquerel (Bq)

[general] The System International unit of RADIATION. The Becquerel defines the number of nuclear decays per SECOND for a quantity of ISOTOPE ($1 \text{ Bq} = 1 \text{ s}^{-1}$), named after ANTONIE HENRI BECQUEREL (1847–1922).

Bel

[acoustics, general, theoretical] A logarithmic SIGNAL scale unit used to express the relative MAGNITUDE of a signal (ACOUSTICS, ELECTRONICS, optical) with respect to a reference value $\text{bel} = \log_{10} I/I_0$. In acoustics, the auditory limit is generally the reference point at $I_0 = 1.0 \times 10^{-12} \text{ W/m}^2$ (associated pressure: a pressure of $P \cong 1.0 \times 10^{-5} \text{ Pa}$). For HEARING, the scale of LOUDNESS is an indication of the number of factors of ten above the threshold of hearing, ranging to $\sim 120 \text{ dB}$ as the threshold of hearing with power density of $I = 1.0 \text{ W/m}^2$ and a pressure of $P \cong 30 \text{ Pa}$. More commonly known under the unit DECIBEL (dB, incorporating the 10-factor): β , in $\text{dB} = 10 \log_{10} (I/I_0) = 20 \log_{10} (A/A_0)$, for AMPLITUDE A . It is named after the scientist ALEXANDER GRAHAM BELL (1847–1922) who initiated the signal qualification process in acoustics.

Bell, Alexander Graham (1847–1922)

[general] A scientist and inventor from Scotland, Great Britain. Alexander Graham Bell provided standardization for electronic design and ACOUSTICS based on his research and industrial involvement. He received the first patent for the telephone in 1876. He was one of the founding fathers of the National Geographic Society. He provided a range of resources and training for the deaf and deaf-mutes, as well as HEARING aid development and processes to assist in communication (see [Figure B.23](#)).

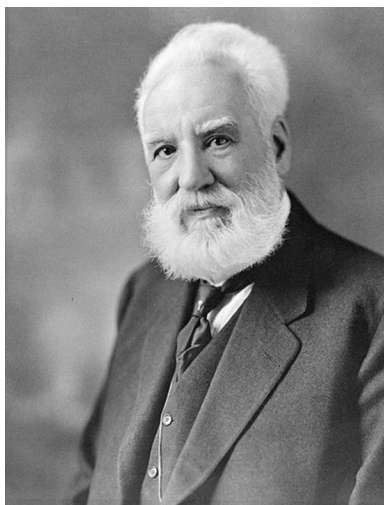


Figure B.23 Alexander Graham Bell (1847–1922). (Courtesy Bibliothèque et Archives Canada.)

Bell, George Howard (1897–1985)

[biophysics, chemical, mechanics] A physiologist and biochemist from the United States who contributed to the theoretical definition of whole MUSCLE strength.

Bell, George Irving (1926–2000)

[biomedical, chemical, computational, mechanics] A biomedical engineer, physicist, and biologist from the United States. Apart from Bell's efforts on the development of the thermonuclear weapon concept and

associated NEUTRON transport, he developed theoretical models related to MUSCLE contraction by means of the description of ADHESION STRENGTH based on ligands in the ACTIN–MYOSIN interaction, next to the models of the MAGNITUDE of immunological events, and played an significant role in the Human Genome project, heading up the Center for Human Genome Studies.

Benedetti, Giovanni Battista (Gianbattista) (1530–1590)

[general] A scientist and mathematician from Italy (Venice, Venetian States) who in 1585 recognized that INERTIA is a phenomenon that can maintain an object in MOTION unless impeded by an external force. This statement was before the work by GALILEO GALILEI (1564–1642) and the laws of motions by SIR ISAAC NEWTON (1642–1727). Benedetti's mathematical efforts focused on Euclid problems. Giovanni Benedetti also worked out a theory of free fall, explaining gravitational acceleration.

Benedict, Francis Gano (1870–1957)

[biomedical] A physiologist, chemist, and nutritionist from the United States. Francis Benedict developed a CALORIMETER and successfully measured metabolic rate; he designed and built a spirometer to determine oxygen consumption. This was all instrumental in the development of our current understanding of the human METABOLISM and scheduling an effective diet. Francis Benedict, with assistance from JAMES ARTHUR HARRIS (1880–1930), produced a heuristic formula for ENERGY expenditure in 1919. The formulation for men and women was different, respectively, male expenditure in calories/day = $(66.473 + 13.752 \times \text{weight}) + 5.003 \times \text{height} - 6.775 \times \text{age}$ and female expenditure in calories/day = $(655.095 + 9.563 \times \text{weight}) + 1.85 \times \text{height} - 4.676 \times \text{age}$, known as the Benedict–Harris equations.

Benedict–Webb–Rubin equation of state

[thermodynamics] An empirical EQUATION OF STATE based on the initial work by JOHANNES DIEDERIK VAN DER WAALS (1837–1923) and the modification introduced in the BEATTIE–BRIDGEMAN EQUATION OF STATE, as performed by MANSON BENEDICT (1907–2006), GEORGE B WEBB (?–?), and LOUIS C. RUBIN (?–?) published in 1940. The Benedict–Webb–Rubin equation of state links the PRESSURE (P), VOLUME (V), and TEMPERATURE (T) of specific substances with the use of coefficients and constants that are listed in look-up tables for a broad range of media, expressed as $P = (RT/V) + (1/V^2)[B_0'RT - A_0' - (C_0'/T^2)] + (1/V^3)(b''RT - A_0') + (a''\alpha^*/V^6) + (1/V^3)\{c''[1 + (\gamma^*/V^2)]/T^2\}e^{-\gamma^*/V^2}$, where A_0' , B_0' , C_0' , and a'' , b'' , c'' , α^* , and γ^* constants that represent the specific properties of the substance.

Berkelium (^{247}Bk)

[atomic, nuclear] A radioactive ELEMENT. BERKELIUM is an actinide, discovered in 1949, artificially created at the University of California, Berkeley, California.

Bernoulli, Daniel (1700–1782)

[computational, fluid dynamics, general] A mathematician from the Netherlands who moved to Switzerland for his professional career. Daniel Bernoulli conceived the equation that described the flow ENERGY balance known as the BERNOULLI'S EQUATION. He also introduced the mathematical format of the series function, later referred to as the BESSEL FUNCTIONS, due to the involvement from FRIEDRICH WILHELM BESSEL (1784–1846). Daniel was a nephew of JACOB BERNOULLI (1654–1705) (see [Figure B.24](#)).



Figure B.24 Daniel Bernoulli (1700–1782), engraved by Johann Jakob Haid.

Bernoulli, Jacob (1654–1705)

[computational] A mathematician from Switzerland. His work made significant contributions in solving separable differential equations. His efforts in PROBABILITY theory and enumeration were published posthumously in 1713 providing proof of mathematical solutions as well as his introduction of the LAW OF LARGE NUMBERS.

Bernoulli number (B_n)

[computational, thermodynamics] A sequence of discrete rational numbers defined through a process of an exponential generating function expressed as $x/(e^x - 1) = \sum_{n=0}^{\infty} (B_n x^n / n!)$. These numbers are invaluable in the series expansions of trigonometric functions, specifically pertaining to number theory and analysis. The number sequence was introduced by JACOB BERNOULLI (1654–1705).

Bernoulli number of the second kind

[computational] A recursive equation, $(b_n = \int_0^1 (x)_n dx)$, used in mathematical modeling and NUMERICAL equation solving, where $(x)_n$ is a coefficient known as a falling factorial that has the parameters expressed by an exponential generating function $E(x)$ as $E(x) = \sum_{k_i=0}^{\infty} (k_i! / a_{k_i}) x^{k_i} = x / \ln(1+x) = 1 + (1/2)x - (2!/6)x^2 + (3!/4)x^3 + \dots$, where a_{k_i} is a coefficient and k_i is an integer.

The **BERNOULLI NUMBER OF THE SECOND KIND** has been defined in many different ways over the centuries after its original conception, published posthumously with respect to the work by **JACOB BERNOULLI** (1654–1705), in 1713.

Bernoulli's equation

[fluid dynamics, thermodynamics] An equation designed by **DANIEL BERNOULLI** (1700–1782) with respect to the **ENERGY** content of inviscid **FLUID** flow, in particular the use of **CONSERVATION OF ENERGY**. The Bernoulli's equation links the gravitational attraction on a volume of medium at elevation h , with density ρ while in **FLOW**, to the kinetic energy density ($KE = (1/2)\rho v^2$, v the velocity) and the applied **PRESSURE** (P) over a **DISTANCE** with different conditions as $P_1 + (1/2)\rho v_1^2 + \rho_1 g h_1 = P_2 + (1/2)\rho v_2^2 + \rho_2 g h_2$, (g is the **GRAVITATIONAL ACCELERATION**) generally considering an **INCOMPRESSIBLE FLUID**, $\rho_2 = \rho_1$, also referred to as the Bernoulli's theorem.

Bessel, Friedrich Wilhelm (1784–1846)

[astronomy, atomic, computational, fluid dynamics, general, geophysics, quantum] A mathematician and astronomer from Germany. Friedrich Bessel redefined the series of equations outlined by **DANIEL BERNOULLI** (1700–1782), known as **BESSEL FUNCTIONS**. Bessel's observations and calculations with respect to the **Hailey's COMET** provided significant detail in the orbital trajectory in 1804. Friedrich Bessel also provided the location in the order of 3222 stars, as well as the **DISTANCE** from the **SUN** to the nearest **STAR**, using an experimental method referred to as parallax (see [Figure B.25](#)).



Figure B.25 Friedrich Wilhelm Bessel (1784–1846), painting by Christian Albrecht Jensen.

Bessel beam

[optics] A nondiffracting beam profile described by a first-order Bessel function ($J_0(k\theta_r r)$), where $\theta_r = \arcsin(n_{\text{lens}} \sin \theta_A) - \theta_A$ is the **DIVERGENCE ANGLE** defined by the axicon angle (θ_A) and the index-of-refraction of the axicon material n_{lens} , r is the radial location, and $k = 2\pi/\lambda$, where λ is the wavelength. The radiance of this beam is constant as a function of position, measured in transverse direction, in the path of propagation. One specific application is found in **LENS-AXICON FOCUSING**, specifically with respect to high-energy pulsed laser **RADIATION**.

Bessel functions

[atomic, computational] A mathematical series formulation introduced by DANIEL BERNOULLI (1700–1782) and generalized by FRIEDRICH WILHELM BESSEL (1784–1846). The Bessel functions are canonical ($y(x)$) EIGENFUNCTION solutions to the Bessel differential equation $x^2(d^2y/dx^2) + x(dy/dx) + (x^2 - \nu^2)y = 0$, where ν is a complex number, indicating the order of the Bessel function. The complex number can take on any value; however, the most relevant solutions are for the integer and half-integer values of ν . Bessel functions of the first kind are defined by $J_\nu(x) = \sum_{m=0}^{\infty} (-1)^m / m! \Gamma(m + \nu + 1) (x/2)^{2m+\nu}$, where $\Gamma(m + \nu + 1)$ is the gamma function ($J_1(x)$ represents a first-order Bessel function of the first kind). The Bessel functions of the first kind are finite at the origin under boundary conditions ν integer or ν real and positive, with the additional condition that when approaching zero for negative nonzero ν . One useful tool is the fact that the Bessel function can be developed in a Taylor series around the origin ($x = 0$). Bessel functions of the first kind for integer $\alpha = n; n \in \mathbb{N}$ can also be formulated as trigonometric integrals $J_n(x) = (1/\pi) \int_0^\pi \cos(n\xi - x \sin \xi) d\xi = (1/2\pi) \int_0^{2\pi} e^{i(n\xi - x \sin \xi)} d\xi$, where ξ is the ANGLE in the complex plane, with the following examples of specific special solutions: $J_0(x) = (1/\pi) \int_0^\pi \cos(x \sin \xi) d\xi = (1/\pi) \int_0^\pi \cos(x \cos \xi) d\xi$, $J_\nu(x) = [(1/2)x]^\nu / \pi^{1/2} \Gamma[\nu + (1/2)] \int_0^\pi \cos(x \cos \xi) \sin^{2\nu} \xi d\xi$, and $J_n(x) = (1/\pi) \int_0^\pi \cos(x \sin \xi - n\xi) d\xi$. An example of the Taylor development is shown in the TERMINAL VELOCITY entry, the torsional oscillations entry, and DIVERGING WAVES entry to name but a few examples. For the case $\alpha = \text{integer}$, the following equality arises: $J_{-n}(x) = (-1)^n J_n(x)$, indicating that the solutions are interdependent; this introduced the Bessel functions of the second kind. Bessel functions of the second kind are combining solutions for the first kind to form: $Y_\nu(x) = J_\nu(x) \cos(\nu x) - J_{-\nu}(x) / \sin(\nu x)$, which converges from $\nu = n; n \in \mathbb{N}$ to $Y_n(x) = \lim_{\nu \rightarrow n} Y_\nu(x)$. Special solutions for the second kind of zero order are $Y_0(x) = (4/\pi^2) \int_0^{\pi/2} \cos(x \cos \xi) \{\gamma + \ln(2x \sin^2 \xi)\} d\xi$. Bessel functions of the third kind are also referenced as HANKEL FUNCTIONS $H_\nu^{(1)} = J_\nu(x) + iY_\nu(x) = i \csc(\nu\pi) \{e^{-i\nu\pi} J_\nu(x) - J_{-\nu}(x)\}$ and $H_\nu^{(2)} = J_\nu(x) - iY_\nu(x) = i \csc(\nu\pi) \{J_{-\nu}(x) - e^{-i\nu\pi} J_\nu(x)\}$. Many solutions can be presented under specific conditions and can be found in SOLUTION books such as *Handbook of Mathematical Functions* by Milton Abramowitz and Irene A. Stegun. Bessel functions form attractive solutions to many complex mathematical and practical problems.

Beta decay (β^-)

[atomic, general, nuclear, solid-state] Two types of DECAY can be distinguished: intrinsic SPIN of electron and NEUTRINO are parallel (GAMOW–TELLER DECAY) or antiparallel (FERMI DECAY). The BETA PARTICLE is similar to an electron and is primarily the result of the breakdown of an ATOM with a PROTON deficiency or excess in neutrons. Due to the ENERGY configuration, the NEUTRON is separated into a proton and an electron or beta particle [β^-] as well as an ANTINEUTRINO ($\bar{\nu}$): $n_{\text{neutron}} = p_{\text{proton}} + \beta^- + \bar{\nu}$. Beta particles are emitted in a continuous energy spectrum, however, with an upper limit. During beta decay, electrons are emitted at relativistic speeds, and classical theory will be insufficient to explain the transmission TUNNELING through the nuclear potential energy BARRIER. This so-called penetrability is described by the relativistic FERMI FUNCTION. The beta-decay spectrum is directly correlated to the transition PROBABILITY: $(1/h) |\mathcal{M}|^2 (dN_{\text{tot}}/dQ_{\beta^-})$, dominated by the density of states of the radio ISOTOPE formulated as $dN_{\text{tot}}/dQ_{\beta^-} = (p_e)^2 \delta(p_e) (dp_{\bar{\nu}}/dKE_{\bar{\nu}}) (L^6/4\pi^4 \hbar^6)$, with $\hbar = h/2\pi$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is the PLANCK'S CONSTANT, N_{tot} is the total number of isotopes, $Q_{\beta^-} = KE_e + KE_{\bar{\nu}}$ represents the beta energy, $|\mathcal{M}|$ is determinant of the matrix defined by the WAVE function (Ψ) ($\mathcal{M} = \int \Psi_D^* \Psi_e^* \Psi_{\bar{\nu}}^* \Delta V \Psi_p dx dy dz$), $L = Mvr$ defines the angular momentum for the mass M at DISTANCE r with velocity v , p_i is the respective momentum for the various particles (p positron; $\bar{\nu}$ antineutrino; e^- electron; β^- beta particle), and $KE_{\bar{\nu}}$ is the kinetic energy for the antineutrino.

Beta particle

[atomic, nuclear, quantum] A charged PARTICLE emitted from the NUCLEUS that has a mass and charge equal in MAGNITUDE to those of the electron.

Bethe, Hans Albrecht (1906–2005)

[astronomy/astrophysics, atomic, nuclear] A physicist from France. Hans Bethe received the Nobel Prize in PHYSICS for his work on explaining and theoretically defining nuclear reactions in 1967. Bethe provided insight into the nuclear ENERGY production in stars (see [Figure B.27](#)).



Figure B.27 Hans Albrecht Bethe (1906–2005). (Courtesy of Los Alamos National Laboratory, Los Alamos, New Mexico.)

Bevatron

[atomic, nuclear] SYNCHROTRON, a PARTICLE ACCELERATOR at Lawrence Berkeley Laboratories, University of California, Berkeley, California, in operation since 1949. Originally, it was designed to accelerate protons, but has been used to accelerate ionized particles as heavy as uranium. The acceleration was produced by a discrete upscaling of the potential difference gradually to 10 MeV (see [Figure B.28](#)).

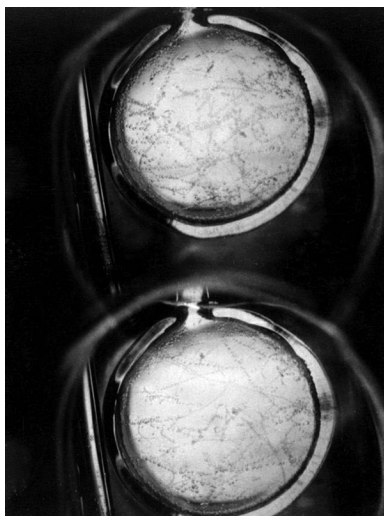


Figure B.28 First charged particle tracks observed in liquid hydrogen bubble chamber at the Lawrence Berkeley Laboratories Bevatron in the 1930s.

B-field

[general] See MAGNETIC FIELD.

Big Bang theory

[astronomy, atomic, general] A theoretical concept of the origin of the UNIVERSE as expressed by ALEXANDER FRIEDMANN (1888–1925) and refined by GEORGE GAMOV (1904–1968). The model of George Gamov assumes that the universe started out as an immensely dense assembly of neutrons, which would be stable in this configuration. Following an implosion, the neutrons were expelled in an explosion that formed other nuclides, grouping to generate the ELEMENTS we now know (listed in the PERIODIC TABLE OF ELEMENTS) or those we still anticipate to find. The big bang event supposedly took place 15×10^9 years ago. Within the first 100 s supposedly, based on ENERGY laws, the first light nuclei were formed, starting out from elementary indistinguishable particles to leptons, quarks, bosons, and photons within the first 1×10^{-34} s. The elementary 1×10^{-43} s on initiation would have been controlled by the “grand unification theories”-based interaction forces, predating the electroweak interaction, forming the leptons and the like (see Figure B.29).

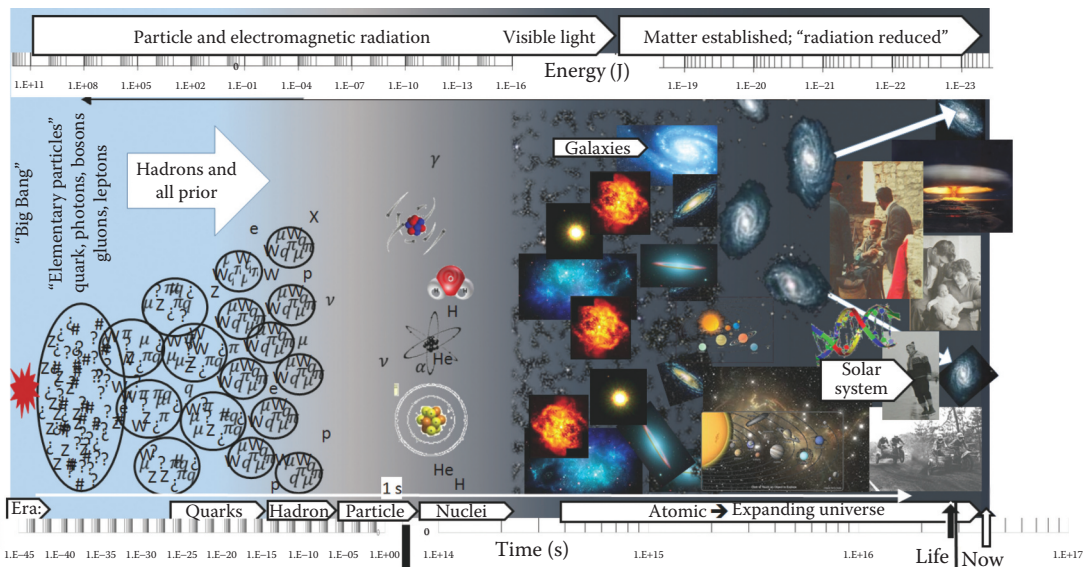


Figure B.29 The hypothetical sequence of events associated with the “Big Bang” process.

Binding energy

[atomic, nuclear, solid-state] The total ENERGY required to separate an ATOM of any ELEMENT with atomic number Z and mass number A into Z individual hydrogen (^1H) atoms as well as N neutrons: $A = Z + N$. This primarily pertains to the splitting of the NUCLEUS into its respective individual nucleons: protons and neutrons, not just the IONIZATION process. The total binding energy for hydrogen ^2H is 2.224574 MeV; for carbon ^{12}C , it is 92.16239 MeV, compared to ^{14}C with 105.28522 MeV; and for uranium ^{235}U , it is 1783.881 MeV. The greater the binding energy, the more stable the element, particularly the binding energy per NUCLEON. The binding energy per nucleon has an apparent peak with 8.7 MeV = 1.394×10^{-12} J per binding at $A \cong 60$, closest element cobalt ^{59}Co (one of the “magic nuclei”). On a related item, the binding energy per PARTICLE is generally different for protons versus neutrons (approximate same mass); however, they are the same for deuterium, although the expelled PROTON will have kinetic energy. The end-product of any FISSION will release the energy difference expressed by the sum of the masses of the fissure components subtracted from the mass of the original atom based on the mass–energy equivalence: $E = mc^2$, with

the speed of light $c = 2.99792458 \times 10^8$ m/s, in addition to accounting for any kinetic energy of the constituents as well as PHOTON emission and elementary particle release.

Bingham, Eugene Cook (1878–1945)

[fluid dynamics, mechanics] A chemist and physicist born in the United States. Bingham made significant mathematical and experimental contributions to the understanding of RHEOLOGY and deformable FLOW (see Figure B.30).



Figure B.30 Eugene Cook Bingham (1878–1945). (Courtesy of Lafayette University, Easton, Pennsylvania.)

Bingham number ($Bm = (\tau_y L / \eta v) = (\sigma_y / \eta Bm \dot{\gamma}_0)$)

[fluid dynamics, mechanics] A representation of the yield-stress ratio to viscous stress within a deformation process, where τ_y is the shear stress, L is the “YIELD LENGTH” or characteristic length, η is the VISCOSITY, v is the velocity, σ_y is the residual stress in the FLOW that stopped, and η_{Bm} is the BINGHAM PLASTIC VISCOSITY. This parameter relates to VISCOPLASTIC liquids and amorphous PLASTICS (e.g., Bingham plastics).

Bingham plastic

[fluid dynamics, mechanics] A FLOW medium with viscometric flow response to applied stress, nonlinear with a threshold stress (σ_0) above which flow is initiated $\sigma_{\text{stress}} - \sigma_0 = \eta \dot{\gamma}$, where $\dot{\gamma} = (dv_x/dx) + (dv_y/dy)$ is the rate of shear combining the directional flow velocity (v_i) gradients in all direction (*Note:* $\dot{\gamma}$ is the temporal derivative of the shear and the stress is $\sigma_{\text{stress}} = F_{xy} / A_{xy}$, the force F_{xy} is parallel to a surface A_{xy}) and η is the VISCOSITY. More formally, the Bingham plastic stress is defined as $\sigma_{\text{stress}} = \sigma_y \text{sgn}(\dot{\gamma}) + \eta_{Bm} \dot{\gamma}_0 (\dot{\gamma} / \dot{\gamma}_0)$, where η_{Bm} is the BINGHAM PLASTIC VISCOSITY and $\text{sgn}(\dot{\gamma})$ return the NUMERICAL sign of the SHEAR RATE value $\dot{\gamma}$ (i.e., $-$; 0 ; or $+$). Some media are SHEAR THICKENING and

SHEAR THINNING under flow. At the point where the threshold is reached in flow reduction, the flow will stop ($\dot{\gamma} = 0$); however, a residual stress (σ_y) will remain (see [Figure B.31](#)).

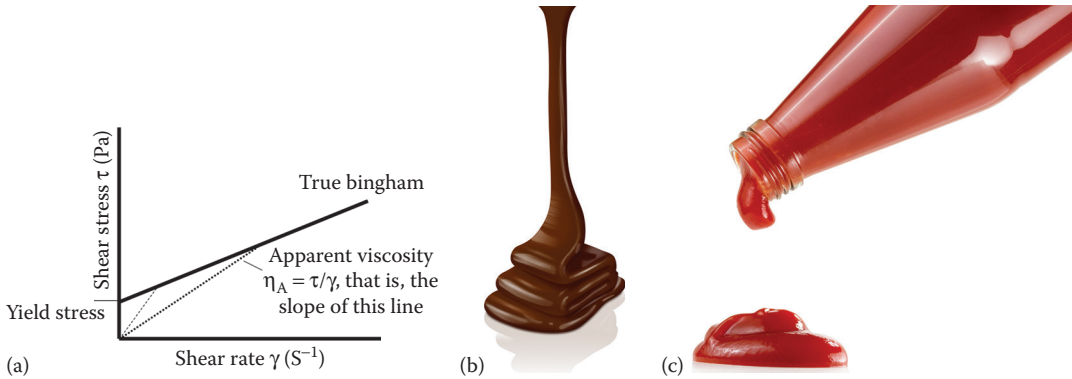


Figure B.31 (a) Graphical representation of the behavior of a Bingham plastic. (b) Example of chocolate as a Bingham fluid and (c) tomato ketchup as a Bingham fluid.

Bingham plastic liquid

[biomedical, fluid dynamics] A material under strain with an associated **SHEAR STRESS** yield value. When the **VISCOELASTIC** material exceeds a certain value, it will **FLOW** as a **FLUID** (e.g., tomato ketchup and toothpaste). The **BINGHAM PLASTIC** fluid has a **RHEOLOGY** that is non-Newtonian but is independent of time (not changing during the process apart from under the influence of the **MAGNITUDE** of the applied shear rate) (see [Figure B.31](#)).

Bingham plastic shear stress

[fluid dynamics, mechanics] A nonlinear description of the shear stress for a medium that deforms under **FLOW**, defined by $\sigma_{Bm} = \sigma_{yield}$.

Bingham plastic viscosity (η_{Bm})

[biomedical, fluid dynamics] The response of the shear stress under the influence of an applied shear rate described as $\eta_{Bm} = \mu_p + \left[\tau_y / \sqrt{[(\partial v_r / \partial \tilde{x})^2 + (\partial v_\phi / \partial \tilde{x})^2]} \right]$, where μ_p is the plastic **VISCOSITY**, τ_y is the parallel shear stress, v_r is the radial velocity, v_ϕ is the angular velocity of **FLOW**, and $\tilde{x}$ is the direction of flow. A Bingham **FLUID** has an inherent offset from the origin to overcome the yield stress in order to accurately characterize the material **RHEOLOGY**. The linear behavior of the shear stress as a function of the shear rate provides the slope in the form of the Bingham plastic viscosity. The shear stress (τ) is a function of the viscosity and the shear rate $\dot{\gamma}$ is given as $\tau = \tau_0 + \eta_{Bm} \dot{\gamma} Y'$, where Y' is the elastic modulus and $\dot{\gamma}$ is the shear rate. Apparent viscosity $\eta_{Bm} = \tau / \dot{\gamma}$ is given by slope of the line.

FLUID	η (mPa s)—ALTERNATIVELY (cP)
Water	1
Coffee cream	10
Vegetable oil	100
Honey	10,000
Asphalt	100,000

Note: cP, centiPoise.

Bioelectrode

[biomedical] An **ELECTRODE** with specific design to collect signals from within a **CELL** either by means of a needle filled with **ELECTROLYTE FLUID** or by an array of electrodes to collect the electrical **DEPOLARIZATION** wave front as a function of location through three-dimensional interpolation, such as a “sock” with a multitude of electrodes that fits around the **HEART** for accurate transmural “imaging” of the depolarization pattern during the systolic event and using volume conduction to locate the exact origin of any irregularities in the depolarization pathway. The irregularities in the ventricular depolarization can identify **MUSCLE** tissue that has been damaged either by lack of oxygen (**CIRCULATION** problems in coronary vessels) or by viral or parasite (e.g., Chagas disease) infections with inflammatory response (see [Figure B.32](#)).

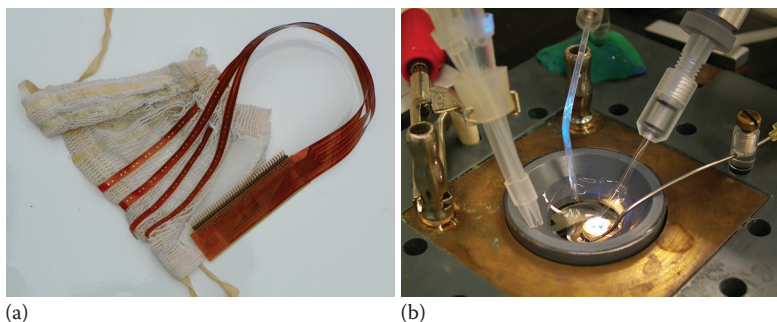


Figure B.32 (a) Example of a bioelectrode. (b) A special kind of electrode called a patch-clamp electrode for electrolyte-mediated recording of ionic potentials.

Bioluminescence

[biomedical, chemical, solid-state] Light emission resulting from **OXIDATION** process in biological systems. One preeminent example is the firefly, and several deep-ocean creatures also emit light. The firefly uses the light **SIGNAL** to attract attention during its mating ritual. There is also evidence that in mammals, in certain cases, cells may communicate with each other through light pulsation. Additional examples of bioluminescence are found in bacteria and fungi. Another description of this process is **CHEMILUMINESCENCE**, based on the chemical foundation, although the chemistry is controlled from biological origin. During the bioluminescence **ACTIVITY**, the biological entity releases specific chemical(s) that are oxidized mediated through a catalyst that employs an enzymatic process. The respective molecule released for oxidation by oxygen under **ENERGY** supplied by adenosine hate is referred to as **LUCIFERIN**, while the catalyst enzyme is branded luciferase. The firefly produces a yellow–green light in pulsating format (see [Figure B.33](#)).

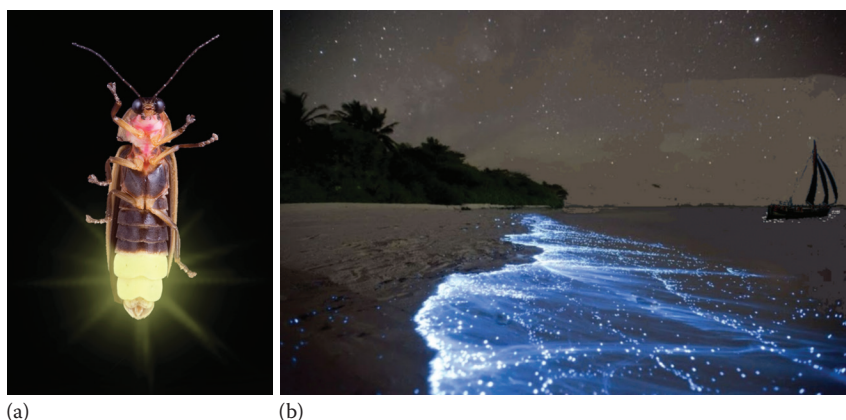


Figure B.33 (a) Image of bioluminescence for a firefly and (b) bioluminescence of algae.

Biomedical optics

[astronomy/astrophysics, biomedical, computational, optics] Theoretical treatise of interaction of ELECTROMAGNETIC RADIATION with biological tissue. The biological media are mixed within the biological entity, creating an inhomogeneous three-dimensional structure where all constituents have specific optical characteristics that are representative of the particular tissues. The optical characteristics are represented by several parameters: absorption coefficient, SCATTERING coefficient, scattering anisotropy factor, and index of REFRACTION, each of which is a function of temperature, wavelength, and density, in turn linked to water content. The light propagation through the turbid biological media can be time dependent, specifically based on periodic biological events affecting the optical characteristics as well as depending on the format of light delivery, pulsed or continuous. The theoretical description of light propagation is derived from earlier work on galactic light propagation, interacting with dust in outer space as well as dust (i.e., various chemical configurations of particulates within a range of sizes) and gasses in the ATMOSPHERE at the location of observation. The early work by ARTHUR SCHUSTER (1851–1934) and KARL SCHWARZSCHILD (1873–1916) published in 1905 and 1906, respectively, provided the time-dependent EQUATION OF RADIATIVE TRANSFER that can be used to describe the three-dimensional propagation of light in turbid media such as biological tissues. The work by Schuster and Schwarzschild was refined in 1918 by FRIEDRICH KOTTLER (1886–1965). The final refinements were made by SUBRAHMANYAN CHANDRASEKHAR (1910–1995) published in 1947. The time-dependent angular and spatial photon ENERGY rate distribution is described by the light power incident on a cross-sectional area flowing within a SOLID ANGLE and is designated by the parameter radiance: $\vec{L}(\vec{r}, \vec{s}, t)$ [W/sr.cm²]. In this notation, the vector $\vec{r}$ denotes the position of the location where the radiance is quantified, $\vec{s}$ is the direction vector for the PHOTON migration, and all as a function of time is t (see EQUATION OF RADIATIVE TRANSFER) (see Figure B.34).

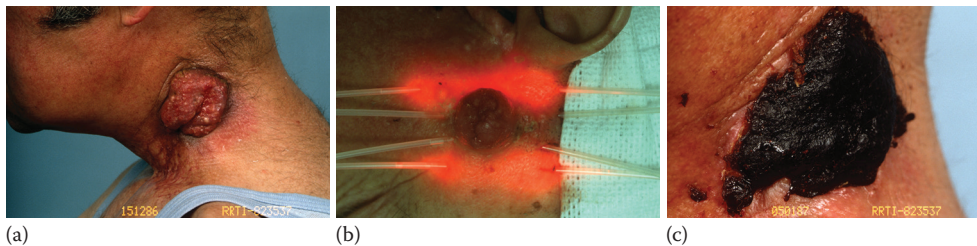


Figure B.34 (a–c) The use of laser to interact with an injectable photochemical that causes cell death in biomedical optics. The cancer treatment of this large cancer growth requires that the illumination is provided from the inside of the tissue volume to overcome the shallow light penetration.

Biophysics

[general] A branch of PHYSICS that integrates physics, biology, chemistry, and ENGINEERING to understand the workings of physiological phenomena as well as the MECHANICS of the ANATOMY and the operational mechanism of action for the various senses. The senses for animals may be different and supplemental to human senses: smell, taste, hearing, sight, touch, and pain (pain is considered a separate sense). Several animals can sense magnetic and electric fields, for instance, sharks for prey identification, and platypus for navigation, next to birds for their migratory path. The BLOOD flow and corrections to FLOW by means of atherectomy or artificial HEART replacement are a FLUID DYNAMICS aspect of biology that are critical for survival. The biological field stretches out from mechanics to fluid dynamics, THERMODYNAMICS, OPTICS, and chemistry. In biology, most physical phenomena are not consistent between individuals and they change over time (COMPLIANCE/time dependence). One specific note on pain: when a pain SIGNAL is processed in the somatosensory area of the parietal lobe of the brain, the location of the source for the pain is registered. Although pain originates from an internal organ, the source of pain may be elusive and misdirected. The action-potential activation of the insular cortex in the frontal lobe of the brain provides an immediate motivation to reverse the cause. In case the frontal lobe has areas that are damaged, one can

feel the pain, but is not motivated to counteract it or remove from the source. The periaqueductal gray area of the brain (midbrain) has the ability to close down the pain gate, thus alleviating the sensation of pain by chemical means. Chemicals such as endorphins affect the periaqueductal gray area by increasing its gate-blocking activity. Endorphins are produced naturally in the brain. Similar externally produced analgesics, such as morphine, also affect the periaqueductal gray area. Additional endorphins can be produced by the pituitary and adrenal glands. These glands release hormones under the influence of external stimuli. One specific example is the phenomenon of stress-induced suppression of pain (analgesia).

Biopotential

[biomedical] An electrical potential generated as the result of a transmembrane gradient in chemical concentration across the cellular MEMBRANE for nerves and MUSCLE as well as other cells for communication and data transfer. The MAGNITUDE of the biopotential is derived with the NERNST EQUATION.

Biot, Jean-Baptiste (1774–1862)

[general] A French physicist. The work of Biot provided the first documented and theoretical proof and definition of OPTICAL ACTIVITY by solutes and solids. The most well-known contributions of Jean Biot are in ELECTRODYNAMICS, specifically his work with FÉLIX SAVART (1791–1841). In 1820, Biot and Savart provided the description of the force on a MAGNET at a DISTANCE from a current in a wire yielding a MAGNETIC FIELD of its own, known as the BIOT–SAVART LAW, also referred to as AMPÈRE’S LAW, more specifically using concepts introduced by ANDRÉ MARIE AMPÈRE (1775–1836) (see [Figure B.35](#)).

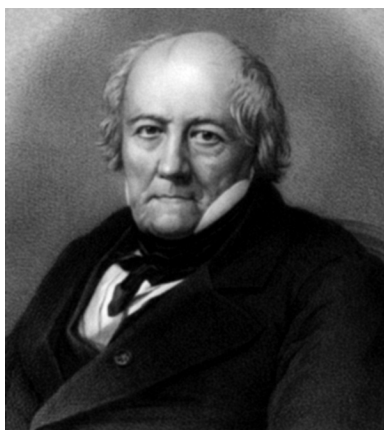


Figure B.35 Jean-Baptiste Biot (1774–1862).

Biot number ($Bi = h_{\text{conv}}L/k_{\text{cond}}$)

[biomedical, thermodynamics] A dimensionless number applied to HEAT TRANSFER. The concept was introduced by JEAN-BAPTISTE BIOT (1774–1862) around 1804 describing the heat transfer conduction within a solid in relation to the convection. The BIOT NUMBER provides the equivalence of conduction and convection with respect to a characteristic length (L), convection coefficient (h_{conv} , convection heat transfer coefficient), and THERMAL CONDUCTIVITY (k_{cond}) of the medium. The BIOT NUMBER is derived using the FOURIER CONDUCTION LAW and NEWTON’S LAW OF COOLING. One ordinary example of the association of this number is that smaller objects cool faster than larger objects. Another implication is that for large objects, the temperature gradient must be very large, specifically for large BIOT NUMBER.

Biot number, mass transfer ($Bi_m = k_{\text{cond}} L / D_{AB} = h_{\text{conv}}^{\text{fluid}} L / D_{AB} \delta_m$)

[general, mechanics, thermodynamics] A dimensionless number relating the mass transfer to HEAT TRANSFER, particularly involving PHASE transitions. The BIOT MASS-TRANSFER NUMBER describes the ratio of “internal diffusion resistance” over the “external diffusion resistance,” where k_{cond} is the THERMAL CONDUCTIVITY of the fluid, D_{AB} indicates the mass DIFFUSIVITY.

Biot–Savart law

[biomedical, computational, electronics, general] Definition of the MAGNITUDE and direction of the MAGNETIC FIELD ($\vec{B}$) resulting from a CURRENT (I) in a length of wire $\Delta \ell$ at a DISTANCE r (i.e., radius of loop of the magnetic field line) from the core of the wire $\vec{B}(r)_x = \mu_m [I(\vec{\Delta \ell} \times \vec{r})_x / 4\pi r^3]$, where $\mu_m = \mu_{mr} \mu_{m0} = \mu_{mr} \times 4\pi \times 10^{-7} \text{ N/A}^2$ is the magnetic permeability, represented by the magnetic permeability of VACUUM ($\mu_{m0} = 4\pi \times 10^{-7} \text{ N/A}^2$) multiplied by the relative magnetic permeability (μ_{mr}), at any location x in the length of the wire. This definition was devised by JEAN-BAPTISTE BIOT (1774–1862) and FÉLIX SAVART (1791–1841) in 1820. This principle was initially investigated in relation to the forces that act on a MAGNET as a result of any combination of nearby currents (*Note:* superposition principle).

Birefringence

[general, optics] Material property. The fact that a ray of light originating from one source (which consists of a finite or infinite number of point sources) traverses the medium in two separate paths. In solids, a medium can have two optical axis that are at an ANGLE to each other. In liquids, the same phenomenon can be achieved through an externally applied electric field, which polarizes the molecules to provide two axis with different index of REFRACTION. The artificially induced birefringence plays a critical role in the KERR EFFECT. The Kerr CELL can be made to change transmissivity on a very short timescale, in sync with the changing applied external electric field. The Kerr effects for liquids have a timescale of less than picoseconds, depending on the MAGNITUDE of the applied field and the constituents of the LIQUID (see Figure B.36).

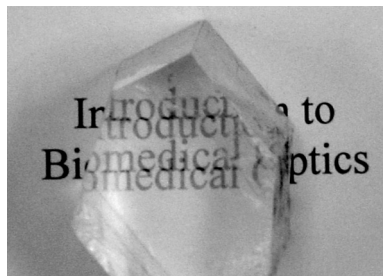


Figure B.36 The birefringence in a crystal, splitting the original text in separate images.

Birge, Raymond Thayer (1887–1980)

[atomic, chemical, nuclear, quantum] A physicist and chemist from the United States. Raymond Birge introduced certain concepts that may be considered QUANTUM chemistry. He was a firm supporter of the BOHR ATOMIC MODEL. His work on the spectral shifts of diatomic molecules, specifically the spectral emission of nitrogen when placed under conditions that create a high degree of DISPERSION, created insight into the ENERGY configuration of the electron orbit in the diatomic nature. His work provided details on the methods of establishing the HEAT OF DISSOCIATION for such diatomic molecules as oxygen, nitrogen, and carbon monoxide using the spectral emission profile. He also provided the most accurate values for constants such as the RYDBERG CONSTANT and Planck's constant (see [Figure B.37](#)).



Figure B.37 Picture of Raymond Thayer Birge around 1920. (Courtesy of Bancroft Library, University of California Berkeley, Berkeley, California.)

Bjork–Shiley mechanical heart valves

[biomedical] An artificial HEART VALVE introduced in 1968 by VIKING OLOV BJÖRK (1918–2009), a Swedish physician and cardiac surgeon, and DONALD PEARCE SHILEY (1920–2010), an engineer from the United States, to replace malfunctioning (not closing properly) bicuspid valves (aortic valve) leading from the left ventricle into the AORTA. The valves open and close due to a fluid-dynamic pressure gradient as a result of the contraction and relaxation of the ventricular MUSCLE of the heart (see [Figure B.38](#)).



Figure B.38 Picture of equivalent Bjork–Shiley mechanical heart valve.

Black, Joseph (1728–1799)

[atomic, general, thermodynamics] A physician from Scotland, Great Britain. Joseph Black was the first person to formulate the concepts of LATENT HEAT and SPECIFIC HEAT. He also discovered the gaseous compound carbon dioxide. He was born in France and resided in his country of nationality Scotland, UK. He introduced the concept of CALORIMETRY and caloric value in 1760. He is a British pioneer in THERMODYNAMICS and introducer of the concept of “the MATTER of heat.” The quantity of HEAT was placed in contrast to the known designation of TEMPERATURE, later translated as CALORIC VALUE, as introduced by Black in 1760. JAMES WATT (1736–1819) was the instrument maker at Black’s university, the University of Glasgow during his time. Black also recognized that carbon dioxide was produced during the metabolic process and was expelled during exhalation. His work is directly linked to the introduction of the ZEROTH LAW OF THERMODYNAMICS.

Black body

[general, nuclear, optics, thermodynamics] A radiative emissive object. A black body readily absorbs and emits thermal RADIATION, with a certain degree of efficacy. The surface absorption efficiency is defined by the spectral absorbance, which is a fractional proportion of the incident ENERGY with respect to the absorbed energy. A perfect absorber has a spectral absorbance of 1: $\alpha_{\lambda}(T) = 1$ (as a function of temperature (T)), defining 100% efficiency. METAL surfaces are generally not perfect absorbers, neither are other polished surfaces. The emission is correspondingly represented by the EMISSIVITY, ranging from $0 \leq \epsilon_{\lambda}(T) \leq 1$. A body that has the maximum absorbing efficiency generally also has equally effective emission of ELECTROMAGNETIC RADIATION due to the thermal agitation of charges at or near the surface (temperature is proportional to the internal kinetic energy). For instance, aluminum foil has $\epsilon_{\lambda}(T) = 0.15$, compared to $\epsilon_{\lambda}(T) = 0.9$ for carbon and $\epsilon_{\lambda}(T) = 0.98$ for exposed human SKIN (considered a perfect black body—no makeup or sunscreen). The thermal agitation of charges in particular presents the process of accelerated charges which, by definition, will produce electromagnetic radiation (as well as absorption under the same concept: CONSERVATION OF ENERGY). The emission process is described by WIEN’S DISPLACEMENT LAW. A highly effective absorber/emitter is referred to as a perfect black body. The spectral profile of a perfect black body follows PLANCK’S LAW of radiative emission. The ideal perfect black body is a box with a rough internal surface (preferably tinted black, but not a requirement) and a small hole; the hole presents the black body, confining all the heat (see Figure B.39).

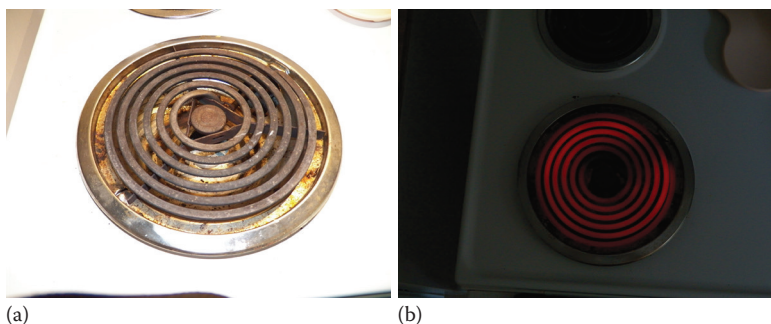


Figure B.39 (a and b) Picture of black body, cold and emitting when hot.

Black-body emission

[astronomy, energy, general, nuclear, optics, solid-state] The RADIANT POWER (P_{rad}) per unit area emitted from a body with EMISSIVITY of a “black body” (emissive object) as a function of emission FREQUENCY (ν) expressed as $P_{\text{rad}} = \left[4\pi h \nu^3 / c^2 \left(e^{h\nu/kT} - 1 \right) \right] \Delta\nu$, where h is the PLANCK’S CONSTANT, k is the BOLTZMANN CONSTANT, and T is the TEMPERATURE (in KELVIN).

Blackett, Patrick Maynard Stuart, Baron (1897–1974)

[astronomy/astrophysics, nuclear] An English physicist who’s groundbreaking work on cloud chambers helped understand the disintegration of isotopes and the trajectory of charged particles. The cloud chamber was instrumental in recognizing the charge state of COSMIC RAYS. Blackett’s interests also included the investigation of PALEOMAGNETISM. He received the Nobel Prize in Physics in 1948 for his work on defining cosmic rays and charge–ray interaction and his experimental verification of annihilation RADIATION. He frequently worked closely with GIUSEPPE (“BEPPO”) PAOLO STANISLAO OCCHIALINI (1907–1993). He was a pupil of ERNEST RUTHERFORD (1871–1937) in the Cavendish (Cambridge, UK) laboratory (see [Figure B.40](#)).



Figure B.40 Picture of Baron Patrick Maynard Stuart Blackett (1897–1974) in approximately 1950.

Black hole

[astronomy/astrophysics, general, quantum, thermodynamics] A galactic phenomenon that apparently captures all mass and ELECTROMAGNETIC RADIATION in its vicinity and will not reemit. The theoretical basis lies in the fact that the mass of the phenomenon is so large that the gravitational force is enormous and interacts even with the electric and MAGNETIC FIELD energies. Keep in mind that GRAVITY is one of the weakest primary forces in the PHYSICS models. The electronic attraction between a PROTON and an electron

is on the order of 10^{40} times stronger than their interrelated gravitational interaction. Mathematically, the interaction of gravity with MATTER is described as the coupling of the gravity vector with the ENERGY-momentum TENSOR of matter. An indication of the phenomenological minimum requirements would be an object with diameter of 15 km and 5 times the mass of the SUN ($m_{\text{black hole}} = 1.0 \times 10^{31}$ kg), yielding a density $\rho_{\text{black hole}} \geq 10^{19}$ kg/m³. The presence of black holes has been identified based on the gravitational influences on nearby bodies as well as diversions in stellar RADIATION patterns. The MILKY WAY also has a verified black hole at its center. Due to the mechanism, the black hole will continue its growth; the black hole in the center of the Milky Way is presumably composed of millions of stars, planets, and “DARK MATTER.” The total mass of a black hole is defined to be confined within the Schwarzschild radius ($R_s = 2GM/c^2$, where $G = 6.673 \times 10^{-11}$ Nm²kg⁻² is the gravitational constant, M is the mass of the object, and $c = 299,792,458$ m/s is the speed of light) (see Figure B.41).

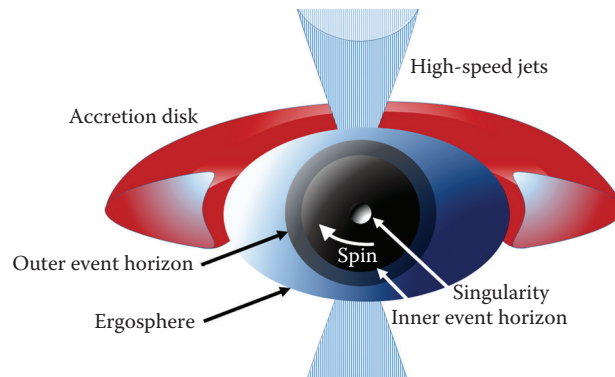


Figure B.41 The configuration of a black hole, based on the efforts from Dr. Luka Č. Popović, Dr. Predrag Jovanović, and Dr. Dragana Ilic, all from the Astronomical Observatory, Belgrade, Serbia.

Black-holes Colliding

[astrophysics, relativistic] Ripples in SPACETIME, time perturbations (see TIME PERTURBATION, COLLIDING BLACK HOLES, GRAVITATIONAL WAVES, and EINSTEIN EQUATIONS).

Blake number ($B\ell = v\rho/\eta(1-\varepsilon)A_s$)

[energy, fluid dynamics] In FLOW through an AGGREGATION of solids (e.g., rock bed) a nondimensional expression to relate the ratio of the inertial to the viscous force. In the representation of the Blake number, the following parameters apply: v is the flow velocity, ρ is the FLUID density, η is the dynamic VISCOSITY, ε is the “bed porosity” or void fraction, and A_s is the characteristic or “bed-specific” surface area. The number is used in momentum transfer as a generalization of the REYNOLDS NUMBER.

Blanc's law

[atomic, condensed matter] The total ION MOBILITY velocity achieved by a mixture of ions moving through a gaseous medium when an external unit electric field is applied μ_{ion} . For a mixture, this translates into $\mu_{\text{ion}} = \left(\sum_{i=1}^n f_i / \mu_{\text{ion},i} \right)^{-1}$, where f_i is the fractional value for constituent i and $\mu_{\text{ion},i}$ is the respective ion mobility.

Blasius, Paul Richard Heinrich (1883–1970)

[computational, fluid dynamics] A German physicist, student of LUDWIG PRANDTL (1875–1953), who in 1908 described the separation of a BOUNDARY LAYER under certain FLOW conditions. Additional work by Blasius provided the expression for PIPE FLOW RESISTANCE in terms of the REYNOLDS NUMBER in 1911. Blasius is a contemporary of THEODORE VON KÁRMÁN (1881–1963) (see [Figure B.42](#)).

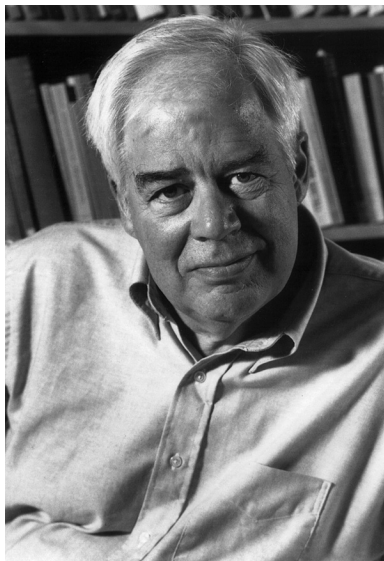


Figure B.42 Picture of Paul Richard Heinrich Blasius (1883–1970).

Blasius' theorems

[fluid dynamics] A FLOW of a medium with density ρ in the $\hat{z}$ -direction around a body will exert a vector force in two dimensions ($\vec{F} = F_x - iF_y$) on this body that is dependent on the flow VELOCITY POTENTIAL (Φ_{flow}) and the contour of the body (C_{contour}), expressed as $\vec{F} = i\rho/2 \int_{\text{contour}} (d\Phi_{\text{flow}}/d\hat{z})^2 d\hat{z}$.

Blatt, John Markus (1921–1990)

[computational, nuclear] A theoretical nuclear physicist and mathematician from Austria. Blatt contributed to the theoretical description of elastic electron collisions as well as SUPERCONDUCTIVITY.

Bloch, Felix (1905–1983)

[atomic, biomedical, nuclear, quantum] A physicist from Switzerland. The contributions of Felix Bloch range from establishing the QUANTUM THEORY of solids to the de Broglie equivalent Bloch waves for electrons. He also provided significant information leading to the description of the magnetic moment for neutrons as well as the BLOCH EQUATIONS that describe the evolution of the magnetic moment with respect to

nuclear magnetization, specifically beneficial for the development of MAGNETIC RESONANCE imaging. He shared the Nobel Prize in PHYSICS with EDWARD MILLS PURCELL (1912–1997) from the United States for their nuclear magnetic work, specifically nuclear magnetic resonance (see Figure B.43).

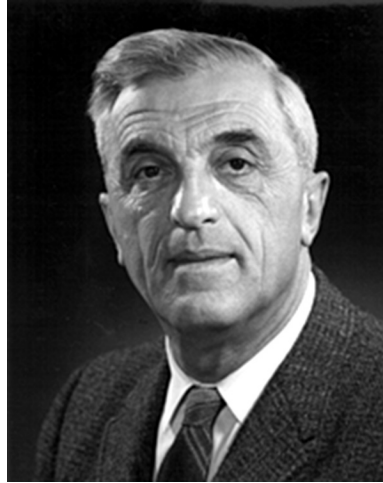


Figure B.43 Picture of Felix Bloch (1905–1983).

Bloch equations

[atomic, biomedical, nuclear] The nuclear magnetization definitions with respect to nuclear MAGNETIC RESONANCE phenomena observed and described by FELIX BLOCH (1905–1983). Using the GYROMAGNETIC RATIO (with respect to the NUCLEUS, the gyromagnetic ratio is $\gamma_N = eg_N/2m_p = g_N(\mu_N/\hbar)$, where g_N is the nuclear g -factor, m_p is the PROTON mass, $\hbar = h/2\pi$ is the Planck's constant with $h = 6.626070040(81) \times 10^{-34} \text{ m}^2\text{kg/s (Js)}$, $\mu_N = e\hbar/2m_p c$ is the nuclear MAGNETON, and c is the speed of light) and nuclear magnetization $\vec{M}(t) = [M_x(t), M_y(t), M_z(t)]$, the magnetic moment of an atomic nucleus that results from the MAGNETIC DIPOLE associated with the SPIN of the protons and neutrons. The Bloch equations for a nucleus exposed to an external time perturbed MAGNETIC FIELD (in the z -direction) expressed by $\vec{B}(t) = [B_x(t), B_y(t), B_0 + \Delta B_z(t)]$ are written as follows:

$$dM_x(t)/dt = \gamma_N [\vec{M}(t) \times \vec{B}(t)]_x - (M_x(t)/T_1),$$

$$dM_y(t)/dt = \gamma_N [\vec{M}(t) \times \vec{B}(t)]_y - [M_y(t)/T_1], \text{ and}$$

$$dM_z(t)/dt = \gamma_N [\vec{M}(t) \times \vec{B}(t)]_z - [M_z(t) - M_0/T_1],$$

where T_1 and T_2 represent the longitudinal and transverse RELAXATION TIME (which will tend to infinity when no relaxation is obtained).

Bloch's theorem

[atomic, biomedical, nuclear] The ENERGY bands in a LATTICE structure have solutions to the SCHRÖDINGER EQUATION $(\Delta\phi_{\vec{k}}(\vec{r}) + (2m/\hbar^2)[KE_{\vec{k}} - V(\vec{r})])\phi_{\vec{k}}(\vec{r}) = 0$, where $KE_{\vec{k}}$ represents the kinetic energy for a PARTICLE with mass $m \cong \hbar^2(\partial KE_{\vec{k}}/\partial \vec{k})$, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant) for a periodically varying potential ($V(\vec{r})$) and have solutions $(\phi_{\vec{k}}(\vec{r}))$, where $\vec{k}$ represents k -SPACE) of the

form $\phi_{\vec{k}}(\vec{r}) = e^{-i\vec{k}\cdot\vec{r}}U(\vec{r})$, where $U(\vec{r})$ represents the internal energy for the crystal lattice with periodicity in $\vec{r}$. This format applies specifically to SEMICONDUCTORS, requiring determination of $KE_{\vec{k}}$ primarily in the first BRILLOUIN ZONE only. The eigenstates of the SOLUTION for an electron in a crystalline lattice are forming Bloch waves, confirming the electronic band structures (formation of electrons in “shells,” with the specific VALENCE and CONDUCTION BAND in reference to the energy structure). The concept was introduced by FELIX BLOCH (1905–1983). It is also known as Bloch WAVE.

Blondlot, Prosper-René (1849–1930)

[atomic, nuclear] A physicist from France known for his controversial and unsubstantiated definition and discovery of so-called N-ray in 1903. The N-ray refers to the hypothetical *neutron radiation*, shortly after the introduction of X-RAY RADIATION by WILHELM CONRAD RÖNTGEN (1845–1923). The failed confirmation of the hypothetical V-ray by his peers created a cautionary attitude in the scientific world toward research based on biased opinion in order to prove a concept, skewing the methods and results.

Blood

[biomedical, fluid dynamics] A biological FLUID that transports oxygen, carbon dioxide, nutrients, and waste products. The oxygen transport relies on the use of hemoglobin enclosed in the red BLOOD CELL. Blood is, due to its particulate structure, a non-Newtonian LIQUID, specifically a shear-thinning liquid (pseudoplast). One may sometimes consider blood as a thixotropic fluid due to the delay experienced for ROULEAUX FORMATION and the response to changes in shear rate. The process of rouleaux formation is the clumping of red-blood cells to form large amalgamations (French for *roll* of blood, resembling a roll of coins) potentially under the influence of abnormal proteins. Rouleaux formation may be considered a rheological abnormality, but it does occur also during pregnancy and as a result of certain FLOW conditions. However, the viscous behavior for blood is a function of the vessel diameter, specifically the flow in capillaries forms a *train* of RED blood cells that are transported as disks that touch the WALL in circumference, balancing the forces, migrating as *parachutes* with significant FRICTION due to indentation of the wall of the vessel. Blood as a transport vehicle for oxygen is perfectly adjusted for the low oxygen content of the Earth's ATMOSPHERE. The oxygen SATURATION CURVE, describing the binding efficacy of oxygen to hemoglobin, is optimized for low oxygen partial pressure. Considering a partial pressure for oxygen of approximately 20.9% O₂ to be $20.9 \times 760 \text{ mmHg} \cong 160 \text{ mmHg} = 2.133 \times 10^4 \text{ Pa}$, the oxygen saturation for blood is relatively level down to 20 mmHg. The blood *consumption* (VO₂) as well as the minute VENTILATION in the alveoli (V_A) determines the drop in partial pressure from inspired to alveolar step in the lung exchange (generally from 150 mmHg to 100 mmHg; *Note*: 20% of oxygen content at an ATMOSPHERIC PRESSURE of 760 mmHg yields a partial pressure for oxygen of free AIR of ~152 mmHg). The partial pressure difference between the oxygen level in the alveoli and the blood in the artery just inside the lung, opposite to the MEMBRANE of the alveoli, is relatively small (~5 mmHg). In the CIRCULATION, starting from arterial stream and tissue exchange, the partial pressure of the oxygen in the blood drops from 95 mmHg to 40 mmHg on the venous side. The arterial to venous oxygen content is a function of the oxygen consumption per minute, the blood flow, and the hemoglobin dissociation curve. The brain controls the RESPIRATION based on the carbon dioxide level only, due to the fact that it affects the pH of the blood (i.e., dissolved provides carbonic ACID, BOHR EFFECT) and can hence be detected by chemical sensors in the blood stream on the vessel wall. In the alveoli of the lungs, there are chemical “transporters” that facilitate the exchange of oxygen and carbon dioxide. Alternatively, carbon monoxide binds permanently to hemoglobin, hence

reducing the oxygen exchange, specifically with respect to cigarette smoke. Nitrogen, as the majority constituent in atmospheric air, is also dissolved in the blood and consequently in tissue. The nitrogen content in the tissue will increase dramatically for deep-sea divers due to the fact that the applied external pressure directly affects the partial pressure of the dissolved gasses in tissues. When the deep-sea divers approach the surface of the water too quickly, the tissue will not have time to gradually release the dissolved nitrogen in the blood stream and will release it quickly in GAS form, creating BUBBLES that form emboli that can result in restrictive blood flow in critical anatomical positions, including the HEART and the brain, causing serious illness and potentially death. The decompression disease is often referred to as CAISSON DISEASE or *the bends* (see Figure B.44).

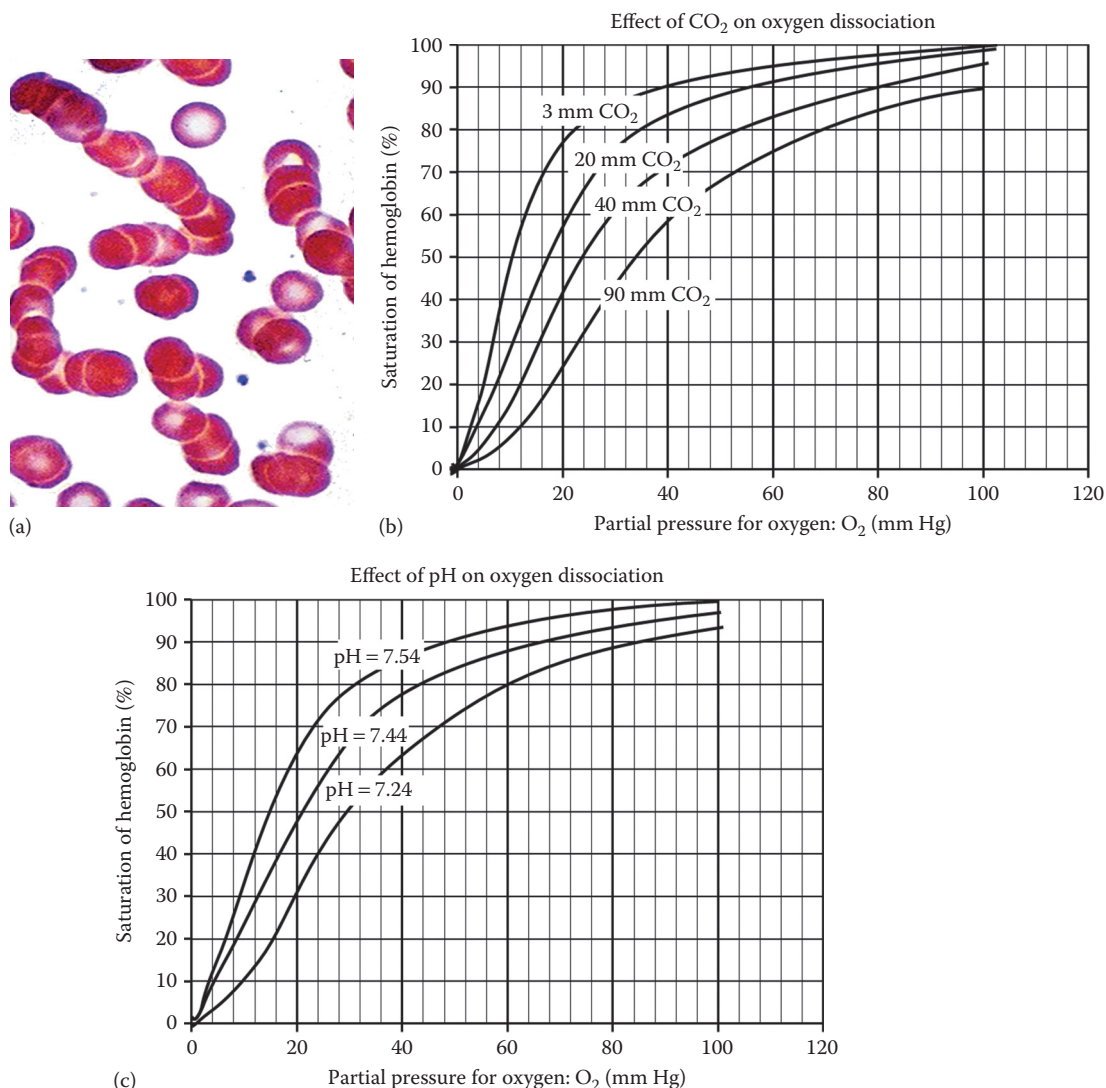


Figure B.44 Blood flow of RBCs in the blood vessel: (a) clumping together of the primary components of blood, the RBCs—rouleaux formation and (b) graphical illustration of the influence of the carbon dioxide concentration in the blood on the oxygen release by the hemoglobin in the RBCs. (c) graphical illustration of the influence of the blood acidity on the oxygen release by the hemoglobin in the RBCs. (Continued)

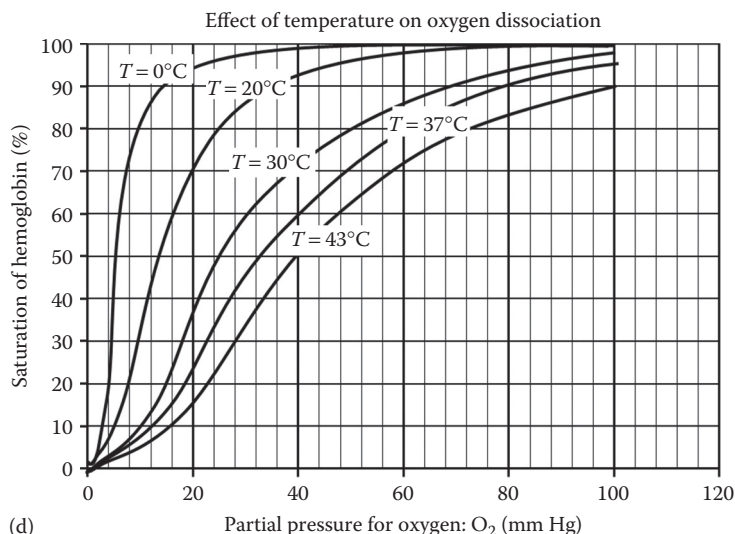


Figure B.44 (Continued) Blood flow of RBCs in the blood vessel: (d) graphical illustration of the influence of the solvent temperature on the oxygen release by the hemoglobin in the RBCs.

Blood pressure

[general] The heart's ventricular contraction provides a pressure (SYSTOLIC PRESSURE) that results in BLOOD flow through the arteries. The COMPLIANCE of the arteries accommodates the sudden increase in blood volume in a restrictive CIRCULATION system, allowing for the pressure to be sustained by the vascular compliance and the surrounding tissue volume that is "pushed aside" as a result of the blood flow. The AORTA is the first vessel attached to the left ventricle leading into the whole body, apart from the pulmonary artery carrying oxygen poor blood from the right ventricle to the lungs. The aortic connection to the brachial artery in the arm provides a relatively reduced pressure profile with respect to the aorta. The brachial artery is accessible in the elbow of the arm and is used for blood pressure measurements by means of the SPHYGMOMANOMETER. The mechanical contraction of the ventricle has a periodic pattern, known as the *heart rate*, providing systolic pressure during contraction and DIASTOLIC PRESSURE during relaxation. The blood pressure in the arm is measured by means of a pressure cuff that will totally close off the brachial artery when inflated to a randomly high pressure in excess of 250 mmHg, the statistically determined highest pressure in the general population. When the pressure cuff pressure is gradually reduced (letting the AIR escape from the bellows at a controlled rate), at one point the pressure in the cuff will match the interstitial pressure applied to the tissue surrounding the artery during systolic blood flow. At this point, a small amount of blood will seep through the narrow opening in the brachial artery, creating a fluttering SOUND similar to allowing air to escape from a balloon by squeezing the opening. The sound made by the blood being forced through the narrow opening generating a tissue VIBRATION was recognized by the Russian physician NIKOLAI SERGEYEVICH KOROTKOV (1874–1920) in 1905. The "Korotkov sounds" are identified by placing a stethoscope in the pit of the elbow. Once the pressure is reduced further, at one point the blood will FLOW freely, referenced as the diastolic pressure. The rate at which the pressure in the cuff is released provides the accuracy and RESOLUTION in the blood pressure diagnosis (slope of the curve, where the curve is composed of

data points acquired at each heartbeat). The two values, systolic and diastolic pressure, are used for clinical identification of problems and health issues associated with either the HEART or vasculature. The normal range is lower than 120/80 mmHg (for a 20-year-old healthy subject); however, these values depend on AGE, where the accepted systolic pressure increases with age. High blood pressure still remains a topic of clinical discussion, and generally, the accepted upper limit for a problematic cardiovascular system is greater than 140/90 mmHg, with specific warning signs for systolic pressure greater than 160 mmHg and diastolic pressure greater than 100 mmHg. The pressure differences as well as ABSOLUTE PRESSURE gradually decline with resistive (vascular diameter) and capacitive (vascular compliance, stretch) DISTANCE with respect to the heart (*also see* WINDKESSEL) (see Figure B.45).

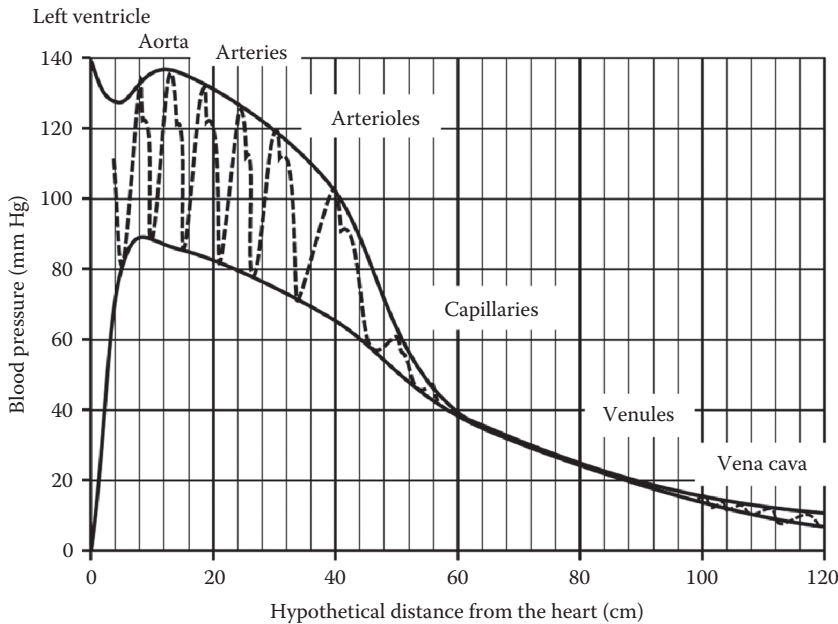


Figure B.45 Graphical representation of the idealized blood pressure in the healthy (average) human circulation with respect to the distance to the heart and the local vessel diameter, depicted by the envelope of the pulsatile flow. The pulsatile (temporal) profile is indicated by a dotted line. The temporal profile also illustrates the dispersion resulting from acoustic impedance based on the vascular compliance and viscous flow constraints.

Blue shift

[astronomy/astrophysics, computational, mechanics, optics] A shift in the spectral line value for verified atomic transitions for specific ELEMENTS to apparently shorter wavelengths due to a relative decrease in proximity between PHOTON emission source and observer. This process is described under *Doppler shift*. The phenomenon relates to the galactic movements of stars with respect to EARTH. The absorption (or emission) lines generally used are the transitions for hydrogen (*see* BALMER LINES).

B-meson

[atomic, general, solid-state] As the B-meson was originally thought to DECAY only to produce either a MUON or a tau, new discoveries have shown a broader range in energies. The charged leptons may indeed not all be equal. The decay processes measured are spread over an ENERGY band that is greater than two times the standard deviation based on the original model (see Figure B.46).

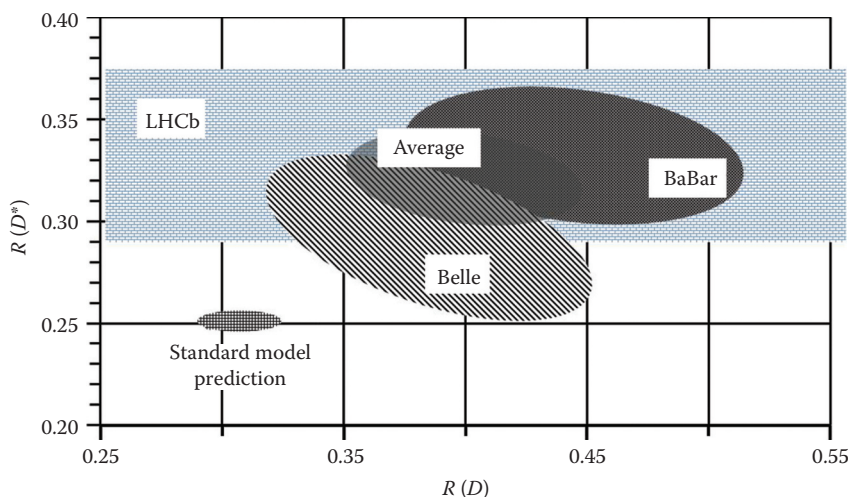


Figure B.46 The experimental results from various groups with regard to the “branching ratios” (R) in relation to the two observed distinct decay processes (D and D^*) in reference to the standard single B-meson model and the average. The unitless branching ratios, representing the decay mechanism of action for the respective B-mesons, observed by the Bell group at the High Energy Accelerator Research Organization, KEK, Tsukuba, Ibaraki 305-0801 Japan, respectively, the Stanford BaBar collaboration (BaBar = B/B-bar system of mesons) at the SLAC National Accelerator Laboratory, Menlo Park, CA (Stanford Linear Accelerator Center), and the LHCb (Large Hadron Collider beauty) collaboration at CERN, European Laboratory for Particle Physics, CH-1211, Genève 23, Switzerland.

Bode, Hendrik Wade (1905–1982)

[communication, electronics, mathematics] A physicist and electrical engineer from the United States.

Bode diagram

[electronics, general] A graphical representation of the frequency response for the MAGNITUDE of a complex quantity of a system (process) as a function of either frequency or PHASE. In electronic applications, the correlation between the complex impedance $Z(f) = \sqrt{(X_c^2 + R^2)}$ and the phase ANGLE $\phi(f) = -\arctg(X_c/R)$ (R is the RESISTANCE and X_c is the capacitive reactance) is called a Bode diagram, named after the efforts from HENDRIK WADE BODE (1905–1982) (see Figure B.47).

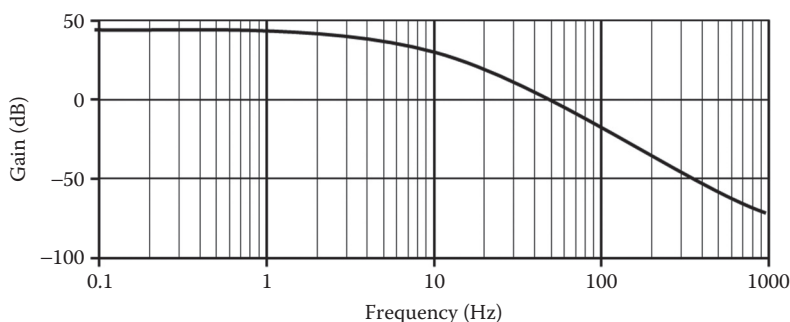


Figure B.47 Bode diagram for a complex electronic alternating current circuit response.

Bodenstein number ($Bs = \nu L / D_{\nu,a}$)

[fluid dynamics] An equation applied to chemical reaction calculations with respect to DIFFUSION, where ν is the velocity, L is the characteristic length, and $D_{\nu,a}$ is the axial DIFFUSIVITY. It can also be considered as the inverse of the PÉCLET NUMBER.

Bohr, Christian Harald Lauritz Peter Emil (1855–1911)

[biomedical] A physiologist from Denmark, father of the physicist NIELS HENRIK DAVID BOHR (1885–1962). Christian Bohr is known for the BOHR EFFECT with respect to the oxygen exchange for BLOOD with respect to the partial pressure of the other constituents of the blood; published in 1902.

Bohr, Niels Henrik David (1885–1962)

[atomic, general, nuclear] A physicist from Denmark. In 1913, Niels Bohr introduced a new concept that the angular momentum of the electrons in the HYDROGEN ATOM has distinct discrete values, equaling $n\hbar$, where $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant. The associated radius for the respective Bohr ORBITS is $r_{\text{Bohr}} = n^2 (0.0529 \text{ nm})$, where $n = 1, 2, 3, \dots$. Niels Bohr received the Nobel Prize in PHYSICS for his work on the atomic model in 1922 (see [Figure B.48](#)).

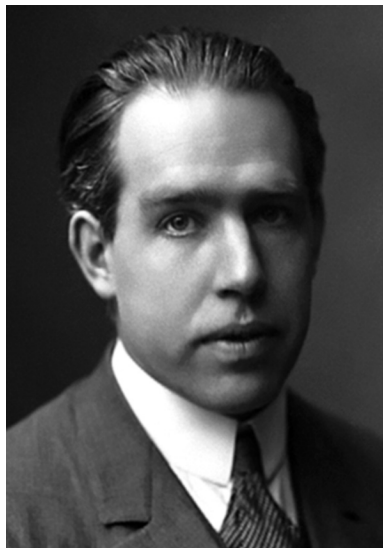


Figure B.48 Niels Henrik David Bohr (1885–1962), anno 1922. (Courtesy of Nobel Prize Organization, Stockholm, Sweden.)

Bohr atom

[atomic, general, nuclear, solid-state, thermodynamics] An ATOM consists of two main components: NUCLEUS and orbiting “PLANET” electrons. This model was developed in parallel with the RUTHERFORD ATOMIC MODEL. Using the information provided by the experimental observations by ERNEST RUTHERFORD (1871–1937) along with JOHANNES “HANS” WILHELM “GENGAR” GEIGER (1882–1945) and ERNEST MARSDEN (1889–1970), and later again supported by HENRY (HARRY) GWYN JEFFREYS MOSELEY (1887–1915), Bohr was able to postulate that the electron-binding ENERGY levels (E_n) are ordered as a function of the “position” relative to the nucleus (identified by the PRINCIPAL QUANTUM NUMBER n , which delineates the DISTANCE to the nucleus: the radius increases by n^2) as follows: $E_n = -\left(2\pi^2 m_e e^4 Q^2 / h^2\right) (1/n^2)$, where m_e is the electron mass, e is the ELECTRON CHARGE, h is the PLANCK'S CONSTANT, and $Q = k_0 Z$ is the ATOMIC NUMBER (Z)

multiplied by the Coulomb force constant (k_0). Based on Planck's observations with regard to the quantization of ELECTROMAGNETIC RADIATION ($E = h\nu$, where h is the Planck's constant and ν is the frequency of light) in addition to the PHOTOELECTRIC EFFECT described by Einstein, in 1908 Niels Bohr formulated his interpretation of the atomic structure. Bohr's atomic model assumptions are as follows: (1) electrons orbit outside the nucleus in discreet stable revolutions $F_{\text{centripetal}} = (mv^2/r) = (e^2/r^2) = F_{\text{electrostatic}}$, where m is the mass, v is the ORBITAL VELOCITY, e is the electron charge, and r is the radius to the core of the atom (the radius of the orbit of the electron); (2) the electronic orbit angular momentum (m_0) has discreet values $m_0 = mvr = nb/2\pi$, where n , an integer, is the principal QUANTUM NUMBER; (3) light is emitted or absorbed in electronic orbital transitions as quantum jumps, each with photonic energy content equal to the difference in orbital energy of the electron $h\nu = E_{\text{initial}} - E_{\text{final}}$. Combining these postulates yields the following expression for the orbit configuration: $r_n = n^2 \left(\frac{h^2}{4\pi^2 m e^2} \right)$, also known as BOHR MODEL OF THE ATOM.

Bohr effect

[biomedical] The principle that the binding of oxygen is affected by both the carbon dioxide concentration and the acidity. The statement made by Christian Bohr in 1902 described that an increase in pH will influence the oxygen affinity of hemoglobin resulting in an increased binding, whereas an increase in carbon dioxide (CO_2) will result in a release of oxygen. Keeping in mind that the additional information became available that dissolved carbon dioxide forms carbonic ACID, hence increasing the pH.

Bohr magneton

[atomic, energy, nuclear, optics] An expression for electron MAGNETIC DIPOLE moment $\mu_B = e\hbar/2m_e c$, where $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, m_e is the electron mass, $e = 1.60217657 \times 10^{-19} \text{ C}$ is the electron charge, and $c = 2.99792458 \times 10^8 \text{ m/s}$ is the speed of light.

Additionally, the Bohr magneton provides an indication of the intrinsic MAGNETIC FIELD associated with the ELECTRON SPIN of an electron in orbit in a BOHR ATOMIC MODEL with MAGNITUDE $\bar{m} = 9.274 \times 10^{-24} \text{ Am}^2$. The orientation of the magnetic moment in this case is in the opposing direction of the angular momentum due to the NEGATIVE CHARGE of the electron.

Bohr method

[biomedical, fluid dynamics] In RESPIRATION, the volume capacity of the lung is measured using this method. The method specifically determines the physiological dead space of the lung total expired volume, named after CHRISTIAN HARALD LAURITZ PETER EMIL BOHR (1855–1911). The physiological dead space (V_D) is the lung volume that is not receiving waste CO_2 from the BLOOD as it flows through the lung vasculature. The AIR expired from the lung is collected over several breaths. The collected expired air is analyzed for P_{e,CO_2} , the partial pressure of carbon dioxide. Subsequently, a collection is made of air forcefully expelled at end expiration, the alveolar air sample, providing the alveolar P_{CO_2} : P_{A,CO_2} . The physiological dead space (V_D) is derived from $V_T P_{e,\text{CO}_2} = (V_T - V_D) P_{A,\text{CO}_2}$, where V_T is the total lung volume.

Bohr model of the atom

[atomic] See BOHR ATOM.

Bohr radius (r_{Bohr})

[atomic, general] A radius of "allowed" ORBITS in the hydrogen atomic model, as defined by the discrete fits $r_{\text{Bohr}} = n^2 (0.0529 \text{ nm})$, where $n = 1, 2, 3, \dots$. This concept was introduced by NIELS HENRIK DAVID BOHR (1885–1962) in 1913, with preliminary expressions in 1908.

Boltzmann, Ludwig Eduard (1844–1906)

[atomic, mechanics, nuclear, quantum] A mathematician and physicist from Austria. Ludwig Boltzmann is best known for his contributions to the statistical description of the behavior and characteristics of gasses and the molecular movement, that is, statistical MECHANICS. Boltzmann's kinematic model predicted the ATOM, but this was not verified until the 1920s after his untimely death (he committed suicide under the assumption that his life's efforts were a waste because no practical evidence could be provided at the time), partially based on the COMPTON SCATTERING experimental results, hence making Ludwig Boltzmann's work a seminal effort. In 1884, Ludwig Boltzmann provided the theoretical argument to verify the black-body RADIATION in collaboration with the work provided by the physicist JOSEPH STEFAN (1835–1893) from Slovenia, in 1879, expressed as the STEFAN–BOLTZMANN LAW (see [Figure B.49](#)).

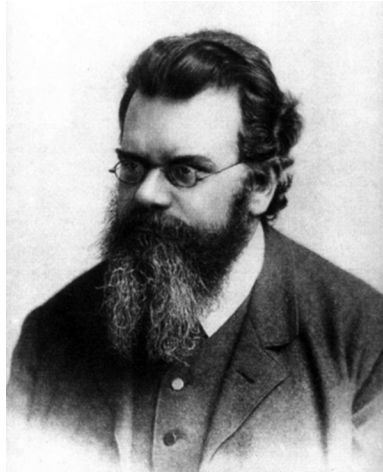


Figure B.49 Ludwig Eduard Boltzmann (1844–1906) taken approximately in 1902.

Boltzmann constant (k_B)

[atomic, fluid dynamics, mechanics, nuclear, quantum] $k_B = R/N_A = 1.38065 \times 10^{-23}$ J/K = $1.3806488 \times 10^{-23}$ m²kg/s²K, where $R = 8.3144621(75)$ J/Kmol is the universal GAS constant and $N_A = 6.022137 \times 10^{23}$ 1/mol is the Avogadro's number. This constant is named after LUDWIG EDUARD BOLTZMANN (1844–1906).

Boltzmann distribution

[mechanics, thermodynamics] A PROBABILITY distribution ($p(E)$) for the states of a system at ENERGY E that is operating at a temperature T in thermal equilibrium $p(E) = (1/P^B) e^{-E/k_B T}$, where $P^B = \sum_i e^{-E_i/k_B T} = \sum_j g_d(E_j) e^{-E_j/k_B T}$ is a NORMALIZATION function over all the states with respective energy E_i , referred to as the PARTITION FUNCTION, $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the Boltzmann constant, $g_d(E_j)$ refers to the DEGENERACY of the respective energy states, and $e^{-E_j/k_B T}$ is the Boltzmann factor. The Boltzmann distribution can also be written with respect to the kinetic molecular theory written in the format of PARTICLE distribution (quantity N and mass m) with respective velocities ($\vec{v}$) as $dN/N = (m/2\pi k_B T)^{1/2} e^{-m\vec{v}^2/2k_B T} d\vec{v}$. The probability distribution was generalized by LUDWIG EDUARD BOLTZMANN (1844–1906) in 1871, based

on the prior work by JAMES CLERK MAXWELL (1831–1879) in 1859. It is also referred to as the Gibbs distribution, the MAXWELL–BOLTZMANN DISTRIBUTION, and the BOLTZMANN'S DISTRIBUTION LAW (see Figure B.50).

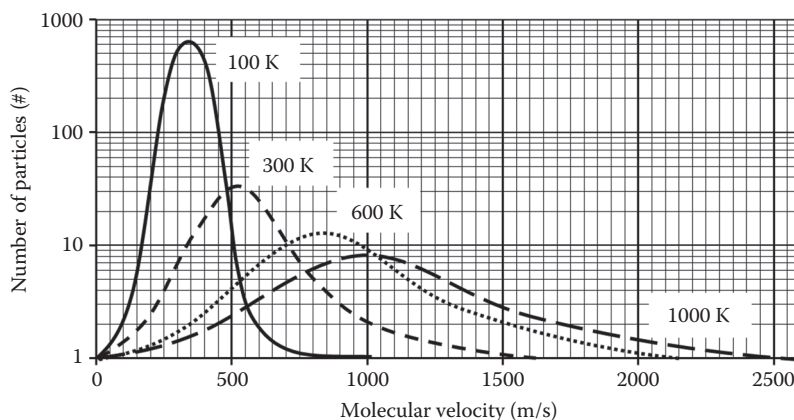


Figure B.50 Boltzmann distribution curve, for respectively four different (arbitrary) temperatures.

Boltzmann equilibrium

[biomedical, computational, general] A statistical thermal equilibrium for a kinetic GAS. The ENERGY exchange for an ISOLATED SYSTEM is in equilibrium.

Boltzmann H-theorem

[computational, energy, mechanics, nuclear, quantum] An expression for the distribution of velocity vectors ($\vec{v}$) in a dilute GAS with respect to the thermodynamic entropy (S). In a dilute gas with finite volume ELEMENTS d^3V , such that one only needs to consider binary collisions, the velocity distribution of the molecules is described by $H^B = \int f(\vec{v}, t) \log f(\vec{v}, t) d^3V$, where the velocity distribution under equilibrium is defined by the Maxwellian function $f(\vec{v}, t) = (m/2\pi k_B T)^{3/2} \exp(-mv^2/2k_B T)$. The equilibrium Maxwellian velocity distribution depends on the THERMAL ENERGY ($k_B T$, where $k_B = 1.38066 \times 10^{-16}$ J/K is the Boltzmann constant and T is the local temperature in KELVIN) and KINETIC ENERGY ($KE = mv^2/2$, where m represents the mass of the gas molecules). When not in equilibrium, the velocity distribution (H^B) decreases monotonically with time.

Boltzmann transport equation

[atomic, general] Semi-classical mechanical description of the migration of particles in a six-dimensional volume for particles at position $\vec{r}$ with momentum $\vec{p} = \hbar \vec{k}$ ($\vec{k}$ is the WAVE number; $|\vec{k}| = 2\pi/\lambda$, λ is the wavelength; $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck's constant). The Boltzmann transport equation describes the rate of change for the parameters of a system defined by the function $f(\vec{k}, \vec{r}, t)$ as a function of time (t), subjected to FLOW and SCATTERING as $(d/dt)f = [\nabla f \cdot (d\vec{k}/dt)]_{\vec{k}} + [\nabla f \cdot (d\vec{r}/dt)]_{\vec{r}} + (\partial/\partial t)f_{\text{scatt}}$, where the last term identifies the contributions from scattering. The function for a FERMI GAS (e.g., electrons in CONDUCTOR) as a function of ENERGY ($\epsilon_{\vec{k}}$) and temperature (T) is defined as $f_0^F(\epsilon_{\vec{k}}, T) = 1/\{\exp[(\epsilon_{\vec{k}} - \mu_c)/k_B T] + 1\}$, where μ_c is the chemical potential and $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the Boltzmann coefficient. For bosons (e.g., phonons), the function adheres to the Bose–Einstein relation as $f_0^B(\epsilon_{\vec{k}}, T) = 1/[\exp(\epsilon_{\vec{k}}/k_B T) - 1]$. When there is no external magnetic or electric field, the system will reach an equilibrium situation, with representative

PARTICLE distribution f_0 . The QUANTUM mechanical equivalent TRANSPORT EQUATION was defined in 1928 by FELIX BLOCH (1905–1983). The transport equation was introduced by LUDWIG EDUARD BOLTZMANN (1844–1906) in 1872 (also see TRANSPORT EQUATION).

Boltzmann's distribution law

[atomic] See BOLTZMANN DISTRIBUTION (also known as Boltzmann's law).

Bond graph

[fluid dynamics, general, mechanics] Graphical representation of the parameters and conditions for a dynamic system, which may be subject to change. Specifically, the ENERGY and work as well as momentum with respect to the DYNAMICS of the system are outlined in blocks in order to solve the individual components of the system in a recursive and interactive manner, based on a block-diagram format. One specific example of a dynamic system that benefits from the use of the Bond graph is the hemodynamic CIRCULATION in the HUMAN BODY. The BLOOD circulation is subject to the periodic MOTION (pressure function) of the HEART (left ventricle) with subsequent vascular COMPLIANCE and vascular branching followed by convergence (arteries to arterioles to capillaries [organs] and converging to venules and veins back to the right side of the heart) (see Figure B.51).

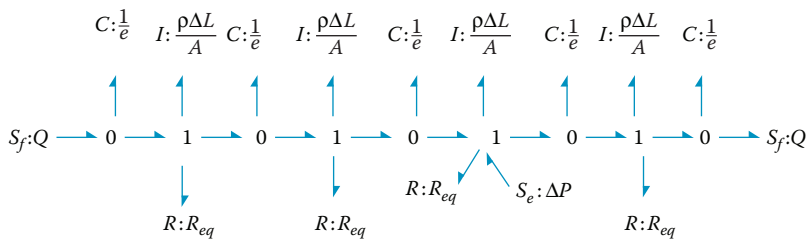


Figure B.51 Bond diagram for a complex and convoluted flow system. Each segment can be solved individually, adhering to the boundary conditions being equal between each sequential tube-flow segment.

Bond number ($Bo = g(\rho_\ell - \rho_v)L^2/\gamma_s$)

[biomedical, fluid dynamics] Dimensionless number describing the range in MAGNITUDE for the ratio between the gravitational force on an object (or buoyance for a BUBBLE) and SURFACE TENSION. In the definition, the following parameters are used: γ_s is the surface tension, L is the characteristic length, g is the GRAVITATIONAL ACCELERATION, and ρ_i is the density of the LIQUID (ℓ) or “submerged” object (v). This number can be used to scale a phenomenon such as the CAVITATION from an object falling into a liquid medium creating cavitation and the potential formation of a water JET as the process develops over time. In another application, bubbles rising through a liquid column are categorized by Bond number. When the Bond number is small, the gravitational force can be neglected in the remaining theoretical analysis (e.g., $Bo \ll 1$) when compared to the surface tension effects as could be the case for a bubble, depending on the boundary conditions. Additionally, undershooting a certain Bond number threshold, the bubbles will not rise in a vertical column (e.g., $Bo < 0.842$). The Bond number can also be used to describe the boundary conditions of the process related to the way a red BLOOD CELL interacts with the CAPILLARY wall in comparison to passing through an artery.

Born, Max (1882–1970)

[atomic, general, nuclear, quantum, thermodynamics] A physicist from Germany. Max Born is most known for his contributions to QUANTUM MECHANICS, and he received the Nobel Prize in PHYSICS for his work on the interpretation of the Schrödinger wave equations in 1953, shared with the German nuclear physicist WALTHER WILHELM GEORG BOTHE (1891–1957) (see Figure B.52).



Figure B.52 Max Born (1882–1970).

Born wave function

[nuclear] NORMALIZATION of the WAVEFUNCTION ($\Psi(x, y, z, t)$ see SCHRÖDINGER EQUATIONS) yielding the PROBABILITY of finding a PARTICLE in a particular VOXEL $dx dy dz$ defined as $\Psi^* \Psi = |\Psi(x, y, z, t)|^2 dx dy dz$.

Born–Oppenheimer approximation

[thermodynamics] A computational approximation for molecular interactions based on the assumption that atomic nuclei have infinite mass and the atomic masses are fixed in space for location (see ADIABATIC APPROXIMATION).

Bose condensate

[computational, energy, fluid dynamics, mechanics, quantum, thermodynamics] Collection of IDENTICAL PARTICLES (particularly bosons) that, when under low temperature conditions (in general below a critical temperature; specifically, approaching ABSOLUTE ZERO Kelvin), act as a single entity, surrendering their individual identities as part of an ISOLATED SYSTEM. Bose–Einstein condensation is considered a PHASE TRANSITION. Under Bose–Einstein condensation, the PARTICLE density (ρ_N , yielding an atomic separation $\sim \rho_N^{-1/3}$) and the temperature (T) are related through the DE BROGLIE WAVELENGTH ($\lambda_{dB} = \sqrt{(2\pi^2 \hbar / m k_B T)}$, Boltzmann coefficient $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg} / \text{s}^2 \text{ K}$, $\hbar = h / 2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg} / \text{s}$ the Planck's constant) as $\rho_N \lambda_{dB}^3 = 2.612$, representative of the lowest energy QUANTUM STATE. The internal energy (U_{BE}) for a GAS with particulate mass m , as a Bose–Einstein condensate $U_{BE} = 4\pi \hbar^2 (\rho_N \mu_{s,a} / m)$, with $\mu_{s,a}$ the characteristic SCATTERING length for s -wave interaction, in the order of 2–5 nm when considering alkali atoms.

Bose liquid

[computational, energy, fluid dynamics, mechanics, quantum, thermodynamics] **BOSON GAS** very close to **ABSOLUTE ZERO** temperature reaching a state of **MATTER** where the majority of bosons are occupying the lowest **QUANTUM STATE**. The quantum effects at this point reach **MACROSCOPIC** scale (see **BOSE CONDENSATE**).

Bose–Einstein statistics

[atomic, nuclear] **QUANTUM**-mechanical description of a system with symmetric **WAVEFUNCTION**, for which the constituents can freely be distributed over the **ENERGY** levels (ϵ_i) for the system. The symmetric wavefunction places the requirement of integer **SPIN** (i.e., bosons). The system can be described by the **PROBABILITY** distribution of particles n_i , which also serves as a representation of the occupation number for the respective (i) energy states, at the temperature T . The energy levels are considered with finite width (hence the “at will” distribution, with g_{ϵ_i} nondegenerate individual energy quantum levels. The probability distribution under Bose–Einstein statistics for the respective energies is $P_{BE} = \prod_i [(n_i + g_{\epsilon_i} - 1)! / n_i! (g_{\epsilon_i} - 1)!] = \prod_i (g_{\epsilon_i}^{n_i} / n_i!)$, with the total number of constituents $N = \sum n_i$ and respective total energy $E = \sum n_i \epsilon_i$. The probability distribution for the occupation of states is now $n_i = g_{\epsilon_i} / C_{BE}^{-1} e^{\epsilon_i / k_B T}$, where $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg} / \text{s}^2 \text{ K}$ is the Boltzmann coefficient.

Boson

[atomic, general] Elementary **PARTICLE** (**GLUON**) named after the physicist **SATYENDRA NATH BOSE** (1894–1974) who provided the critical information with respect to the description and discovery. Bosons provide the vehicle for the strong interaction between quarks. The boson has integer **SPIN** values (in contrast to fermions with half-integer spin, named after **ENRICO FERMI** [1901–1954]). Specific vector bosons are W^+ , W^- , and Z particles as well as the **PHOTON**.

Boson gas

[thermodynamics] A system of particles that satisfies the Bose–Einstein condensate criteria (see [Figure B.53](#)).

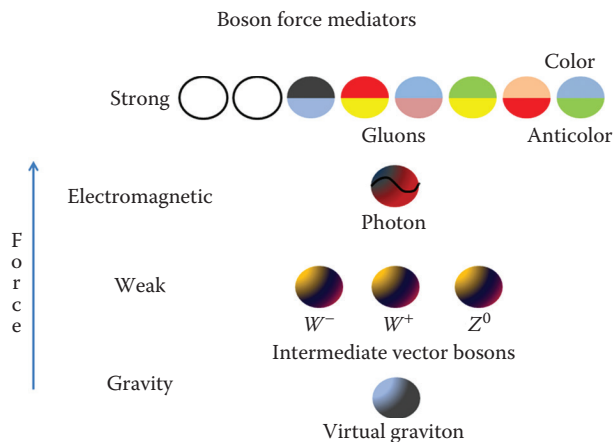


Figure B.53 Boson.

Bothe, Walter Wilhelm Georg (1891–1957)

[atomic, nuclear, thermodynamics] A German scientist who worked on the nuclear program and shared the Nobel Prize in PHYSICS in 1954 with MAX BORN (1882–1970).

B

Boulton, Matthew (1728–1809)

[thermodynamics, mechanics] A Scottish engineer, partner of JAMES WATT (1736–1819). Together they produced steam engines used to drain mines. Later applications of steam engines produced by Boulton and Watt were in the original field of Boulton, coin stamping (see [Figure B.54](#)).



Figure B.54 Matthew Boulton (1728–1809), painting by Carl Frederik von Breda, c. 1792.

Boundary layer

[fluid dynamics] A concept introduced by LUDWIG PRANDTL (1875–1953) in 1905. Fluid-element layer of molecules from the surrounding FLUID covering the surface of a solid body subjected to a fluid in rest or in MOTION that is not subjected to the same parameters as the whole LIQUID. Basically, the boundary layer is a transition from the fluid to the mechanical conditions of the object. Outside the boundary layer, the INVISCID FLOW is behaving similar to all the fluid, with perturbation for localized vector direction based on the dimensions of the object obstructing the flow (see [Figure B.55](#)).

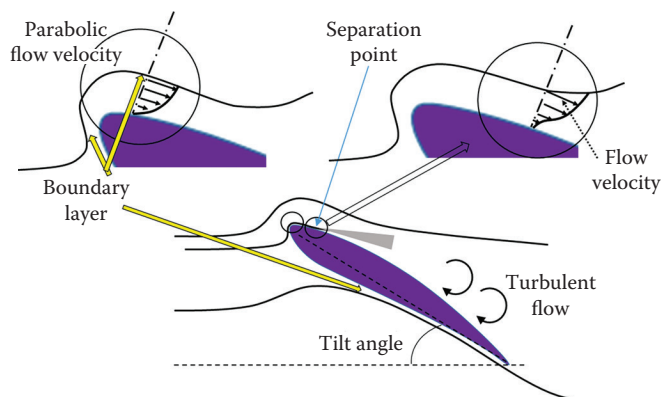


Figure B.55 Boundary layer aspect of flow, for instance, with respect to an airfoil (wing). The detachment of the boundary layer forms the onset of turbulent flow.

Boundary layer, main flow

[fluid dynamics] A transition layer between fixed surface and main flow region of uniform flow velocity. The velocity at the surface is zero due to FRICTION and ADHESION, the layer with a high gradient in velocity is the boundary layer, until the region is reached where the FLOW is uniform through the remaining volume of flow. On the face of the body, the flow velocity is zero with absolutely no slip. For this reason, owing to the effect of friction the flow velocity near the WALL varies continuously from zero to uniform velocity. In other words, it is found that the surface of the body is covered by a coat comprising a thin layer where the velocity gradient is large. This layer forms a zone of reduced velocity, causing vortices, called a WAKE, to be cast off downstream of the body.

Boyle, Robert (1627–1691)

[atomic, chemical, energy, general, nuclear] A scientist from Ireland. The work of Robert Boyle on gases followed by the efforts of the French scientist JOSEPH LOUIS GAY LUSSAC (1778–1850) formed the gateway to modern GAS theory and the IDEAL GAS LAW. Additional contributions were in the fields of pneumatics and chemistry (see [Figure B.56](#)).



Figure B.56 Robert Boyle (1627–1691).

Boyle's gas law

[general, fluid dynamics, thermodynamic] See **BOYLE'S LAW**.

Boyle's law

[atomic, fluid dynamics, mechanics, nuclear] For an isothermal process, the pressure–volume relationship can be defined as $PV = \text{constant}$. During an ADIABATIC PROCESS ($T \neq \text{constant}$), the pressure will drop faster with increasing volume than for an isothermal process and a correction is required, which has been established empirically as $PV^\gamma = \text{constant}$, where the exponential factor γ depends on the process and the medium. For a monoatomic GAS, $\gamma = 1.67$, while for a diatomic and polyatomic gas, the values are, respectively, $\gamma \cong 1.4$ and $\gamma \cong 1.3$. The “IDEAL GAS LAW” still hold true. The correlation between volume and pressure

at constant temperature was described earlier by EDMÉ MARIOTTE (1620–1684) from France in 1650, hence also known as Mariotte's law. Since it was introduced by ROBERT BOYLE (1627–1691), it is also known as BOYLE'S GAS LAW (see Figure B.57).

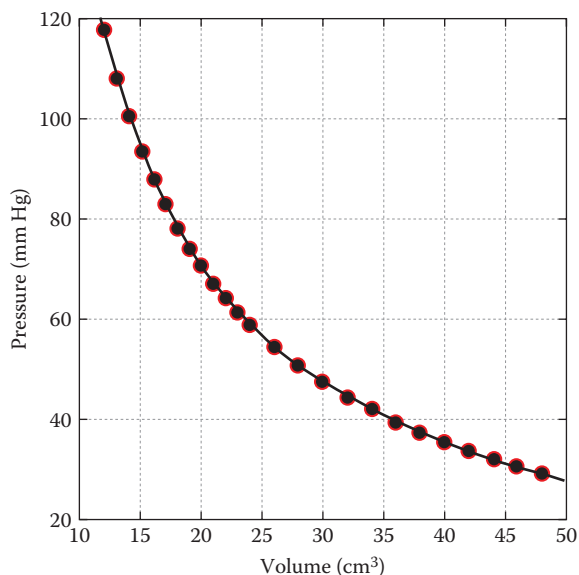


Figure B.57 Boyle's law in graphical form using the data as published by Robert Boyle.

Boyle–Charles' law

[fluid dynamics] An IDEAL GAS LAW based on the observations of ROBERT BOYLE (1627–1691) and refined by the French scientist JACQUES ALEXANDRE CÉSAR CHARLES (1746–1823). Jacques Charles recognized that for a fixed quantity of dilute gas (closed volume) under constant pressure, the volume is directly proportional to the applied ABSOLUTE TEMPERATURE (in KELVIN) (see IDEAL GAS LAW).

Boyle–Gay Lussac's law

[fluid dynamics, general, thermodynamic] Equilibrium conditions between VOLUME (V), PRESSURE (P), and TEMPERATURE (T) for a dilute GAS: $PV = nRT$ or $P_1V_1/T_1 = P_2V_2/T_2$, where $n = N/N_A$ represents the number of MOLE of medium (N is the number of molecules and N_A is the Avogadro's number) and R is the universal gas constant.

Bragg, William Henry, Sir (1862–1942)

[general] A scientist from Great Britain. He is an experimentalist on crystal diffraction and a contributor to the BRAGG'S EQUATION with his son WILLIAM LAWRENCE BRAGG (1890–1971).

Bragg, William Lawrence, Sir (1890–1971)

[atomic, general, nuclear] A scientist from Great Britain. He is an experimentalist on crystal diffraction and a contributor to the BRAGG'S EQUATION with his father SIR WILLIAM HENRY BRAGG (1862–1942) (see Figure B.59).



Figure B.59 Picture of the team at the laboratory of William Lawrence Bragg (1890–1971), c. 1931.

Bragg plane

[atomic, nuclear, solid-state] SIR WILLIAM LAWRENCE BRAGG (1890–1971) modeled a LATTICE constructed with parallel planes of symmetry, separated by a periodically reproduced DISTANCE, in various sectional directions, not specifically parallel to the surface plane of the lattice. The planes can be identified from diffraction experimentation using X-RAY diffraction based on the BRAGG'S EQUATION. Plane of a lattice structure bisects one reciprocal lattice vector (wavevector: $k = 2\pi/\lambda$, where λ is the wavelength), defined in the RECIPROCAL SPACE (also see BRAVAIS LATTICE and MAX THEODOR FELIX VON LAUE) (see Figure B.58).

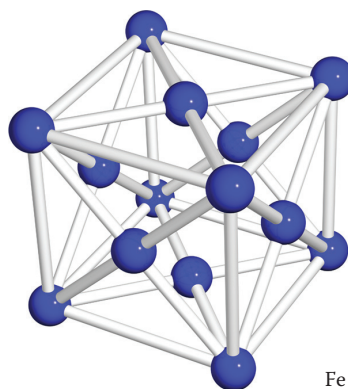


Figure B.58 The Bragg plane in a crystal structure.

Bragg's diffraction

[atomic, nuclear] See BRAGG'S EQUATION.

Bragg's equation

[nuclear] A mechanism of action for diffraction of ELECTROMAGNETIC RADIATION proposed by the father-and-son team Sir WILLIAM HENRY BRAGG (1862–1942) and Sir WILLIAM LAWRENCE BRAGG (1890–1971)

based on the preliminary experimental work by the German physicist MAX THEODOR FELIX VON LAUE (1879–1960). The location with respect to the DIFFRACTION GRATING for constructive INTERFERENCE between diffracted rays is given by the equation $2d \sin(\theta_m) = m\lambda$, where d is the GRATING spacing (the regular spacing between the atoms in the crystal structure), m is the diffraction order number ($m = 1, 2, 3, \dots$), θ_m is the diffraction ANGLE or angle of observation, and λ is the wavelength of the electromagnetic radiation (e.g., X-RAY and light), also referred to as BRAGG'S LAW.

Brahe, Tycho {Tyge Ottesen Brahe} (1546–1601)

[astronomy/astrophysics, general] A scientist and nobleman born in Denmark. Tycho Brahe made detailed observations on the planetary motions, which helped JOHANNES KEPLER (1571–1630) formulate his THREE LAWS OF PLANETARY MOTION. He made considerable improvements on the optical quality of TELESCOPE construction and obtained significant details on events in the UNIVERSE. He discovered a SUPERNOVA (i.e., birth of a new STAR) in 1572. He also observed the trajectory of a passing COMET in 1577, providing critical information about gravitational forces. Nevertheless, his solar model was still GEOCENTRIC, based on the teachings of NICOLAUS COPERNICUS (1473–1543) and CLAUDIUS PTOLEMY (approximately AD 90–168) (see [Figure B.60](#)).



Figure B.60 Painting of Tyge Ottesen Brahe [Tycho Brahe] (1546–1601) by Eduard Ender.

Bravais lattice

[condensed matter, solid-state] A crystal structure with various configurations with respect to the centering of the LATTICE. In atomic structure, a total of fourteen (14) Bravais lattices can be defined based on their geometric composition, per respective lattice system: triclinic; monoclinic: base-centered and simple cubic monoclinic; orthorhombic: base-centered, simple orthorhombic, face-centered, and body-centered orthorhombic; rhombohedral; tetragonal: body-centered and simple cubic rhombohedral; and cubic: simple cubic, face-centered cubic, and body-centered cubic. The rocksalt (sodium chloride: halite) structure is an octahedral configuration, forming a three-dimensional checkerboard pattern. The zinc blende structure has tetrahedral coordinates but is not fully defined as such. The structure of the zinc blende is similar to the diamond structure, although without the regular atomic structure, instead alternating types of atoms at

the lattice corners. The planes of organization within the lattice are defined through their respective Miller index (see Figure B.61).

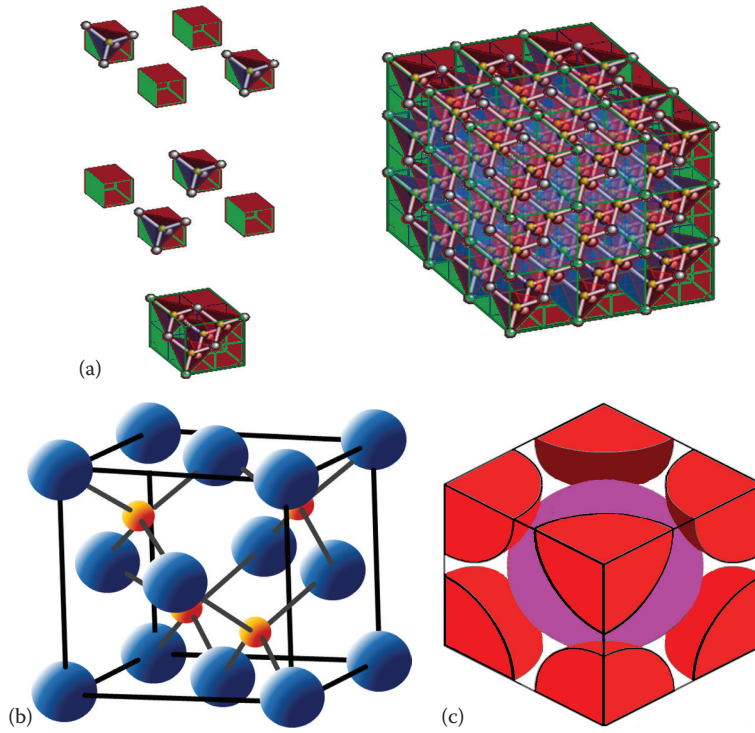
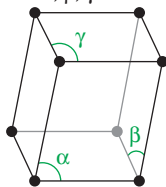
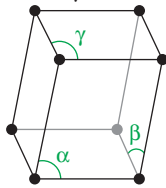
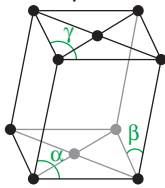
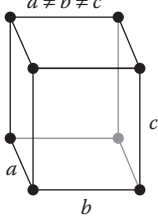
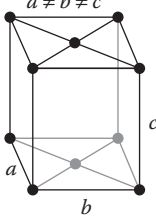
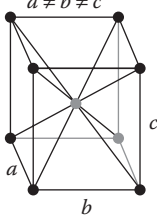
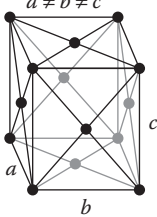
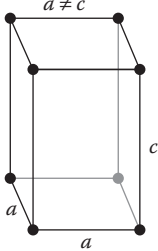
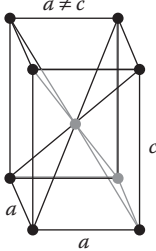
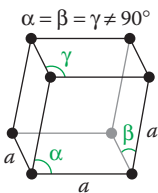
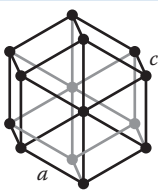
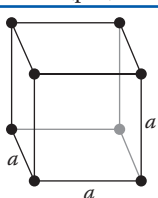
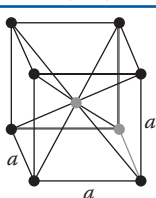
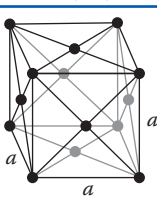


Figure B.61 (a–c) Illustrations of the structure involved in Bravais lattice configurations.

LATTICE SYSTEMS (7)	BRAVAIS LATTICES (14)			
Triclinic	P			
	$\alpha, \beta, \gamma \neq 90^\circ$ 			
Monoclinic	P	C		
	$\beta \neq 90^\circ$ $\alpha, \gamma = 90^\circ$ 	$\beta \neq 90^\circ$ $\alpha, \gamma = 90^\circ$ 		

(Continued)

LATTICE SYSTEMS (7)	BRAVAIS LATTICES (14)			
Orthorhombic	P	C	I	F
				
Tetragonal	P	I		
				
Rhombohedral	P			
				
Hexagonal	P			
				
Cubic	P (pcc)	I (bcc)	F (fcc)	
				

Bremßstrahlung

[atomic, biomedical, general, nuclear] See **BREMSSTRAHLUNG**.

Bremsstrahlung

[atomic, biomedical, general, nuclear] RADIATION created by the impact of high ENERGY electrons on a medium with high MOLECULAR WEIGHT. The electrons are accelerated in a negative manner, creating radiation with energy equivalent to the electron impact, resulting in X-RAY radiation. The specific X-ray spectrum created is a function of the atomic structure of the target. The maximum energy E released as radiation $E = h\nu$, where $h = 6.6260755 \times 10^{-34}$ J s is the Planck's constant and ν is the frequency of the radiation, will equate to the kinetic energy of the electron $E_{\text{kin}} = (1/2)mv^2 = e * V$, where V is the voltage applied to induce acceleration of the electron with charge e and mass m moving with final velocity v . Note that the frequency in this case will be the upper limit ν_{max} , yielding a minimum X-ray WAVELENGTH (as pertaining to the maximum RESOLUTION defined by the RAYLEIGH CRITERION) as $\lambda_{\text{min}} = c * (h/e * V)$.

Brewster, David (1781–1868)

[general] A physicist from Great Britain. David Brewster provided particular information with regard to light POLARIZATION, specifically known as BREWSTER'S LAW or the BREWSTER'S ANGLE (see [Figure B.62](#)).



Figure B.62 David Brewster (1781–1868) c. 1850.

Brewster's angle (θ_p)

[general] An ANGLE of incidence for light reflecting from the interface between two media with index of REFRACTION: incident from medium with index n_1 and reflecting at medium with index n_2 resulting in propagated light with LINEAR POLARIZATION in the direction perpendicular to the PLANE OF INCIDENCE (for a perfectly flat, semi-infinite medium, the POLARIZATION is thus parallel to the plane of interface).

The minimum angle (θ_p) of incidence required to provide perfectly polarized light is defined as $\tan \theta_p = n_2/n_1$. One specific application is found in the Nicol prism (see Figure B.63).

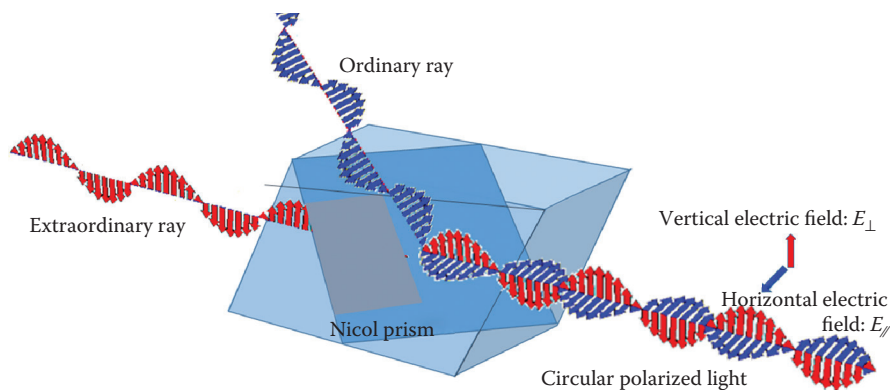


Figure B.63 Brewster angle in Nicol prism providing orthogonal polarization of the split beams.

Brewster's law

[general] See **BREWSTER'S ANGLE**.

Brillouin zone

[computational, electronics, quantum, solid-state] A concept used with respect to “density of states” relating to electron charges in solids and liquids. On a crystal structural level, a primary configuration can be identified that defines the outline of a primitive unit CELL that confines all the symmetry properties of the entire crystal in repetition, named the Wigner–Seitz cell. For the crystal, the first Brillouin zone defines the Wigner–Seitz cell with respect to the reciprocal atomic LATTICE in k -SPACE in a BRAVAIS LATTICE (k represents the wavevector: $k = 2\pi/\lambda$, where λ is the wavelength). The regularity of the atomic lattice provides the framework for the eigenvalues of the WAVE EQUATION solutions, that is, electronic eigenstates. Traveling electron waves (i.e., Bloch wave) through the lattice with WAVELENGTH (modulation) matching the periodicity of the polyhedron crystal lattice structure are in the first Brillouin zone. On an acoustic basis, the wave is referred to as a vibrational QUANTA, a phonon. Additional reference to the FERMI SURFACE will be required for full definition of the Bloch wave, where the Fermi ENERGY is the upper primary limiting factor. The second Brillouin zone may be reached from within the first Brillouin zone by means of crossing a single BRAGG PLANE only.

Brinkman, Henri Coenraad (1908–1961)

[fluid dynamics] A scientist from the Netherlands. Henri Brinkman is best known for his work on VISCOSITY, specifically viscous dissipation. The work of Henri Brinkman was based on the Darcy equation from the French engineer Henry Philibert Gaspard Darcy (1803–1858).

Brinkman number ($Br = \eta v^2 / \kappa_{\text{cond}}(T - T_0)$)

[fluid dynamics] A number that indicates the viscous dissipation, where v is the velocity, η is the VISCOSITY, $\kappa_{\text{cond}} = 75k/64r^2 \sqrt{kT/\pi m}$ is the THERMAL CONDUCTIVITY of the FLUID k the Boltzmann constant, r is the radius of the hard sphere that is in FLOW, m is the molecular mass (*Note: the universal GAS constant: $R = k/m$*), T is the temperature of the boundary (WALL), and T_0 is the bulk fluid temperature. This phenomenon generally applies to the CONTINUUM (*see* **KNUDSEN NUMBER**).

Brinkman number, modified ($Br^* = (T - T_0)_{\text{iso}} / (T - T_0)$)

[fluid dynamics] A number that indicates the viscous dissipation, where T is the temperature of the boundary (WALL) and T_0 is the bulk FLUID temperature, and iso denotes isothermal conditions while all objects are moving at identical bulk VELOCITY (*also see* **BRINKMAN NUMBER**).

British thermal unit (Btu)

[general] A unit of heat or work. In heat, the Btu represents the ENERGY requirement to raise one (1) British pound of WATER (1 lb = 453.59 g) by one (1) degree Fahrenheit: 1 Btu = 1055.05585 J.

Brown, Robert (1773–1858)

[biomedical, nuclear, solid-state] A scientist, biologist, and botanist from the United Kingdom (specifically Scotland). His primary observations leading to his description of BROWNIAN MOTION were performed on moving cells under a MICROSCOPE, specifically related to his work on fertilization (as well as pollination) and the movement of sperm. He observed particle MOTION in liquids, such as pollen in water, apparently randomly moving about. This was later described as molecular and particulate collisions by ALBERT EINSTEIN (1879–1955). The phenomenon can sometimes be observed during fine snow-dust precipitation (not real snowflakes, equivalent to suspended frozen mist) under the absence of wind while there is a LIGHT SOURCE providing contrast (e.g., the SUN; causing reflections that can be traced). The thermal gradients in the AIR near buildings can provide a MACROSCOPIC TURBULENCE, moving the floating frozen ice specks in collision-based random orientation (*see* [Figure B.64](#)).



Figure B.64 Robert Brown (1773–1858), approximately 1855.

Brownian motion

[atomic, biomedical, computational, nuclear, solid-state] A STOCHASTIC PROCESS of random movement of particles in colloidal suspension (in liquids or gasses, and even on atomic and molecular level) as a result the thermal MOTION (~kinetic ENERGY) of the particles in the suspending medium. It has been postulated that ELEMENTARY PARTICLES may also perform Brownian motion, subject to nuclide collisions. It was first described by ROBERT BROWN (1773–1858) in 1827. The principle is also applied in NUMERICAL theory, referred to as “particle theory.” The PARTICLE interaction was described on an interactive gravitational scale using the gravitational length: $\ell_g = k_B T / m^* g$, where $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ is the Boltzmann constant, T is the local temperature, m^* is the mass of a GAS molecule, and g is the GRAVITATIONAL ACCELERATION.

Brunt–Väisälä buoyancy frequency of the atmosphere

[astronomy/astrophysics, fluid dynamics, geophysics] OSCILLATION frequency (v_{BV}) of a column of AIR around an equilibrium position in altitude z_0 during adiabatic MOTION, provided as the result of BUOYANCY of a LIQUID, at ABSOLUTE TEMPERATURE with respect to a reference temperature under constant pressure: $T/T_0 \sim \theta/\theta_0$ ($\theta = T(P/P_0)^{\kappa_g}$, $\kappa_g \equiv R/c_p = \gamma_c/(1-\gamma_c)$, c_p is the SPECIFIC HEAT under constant pressure, $\gamma_c = c_p/c_v$, where θ defines the potential temperature), yielding $v_{BV}^2 = g[d(\ln \theta_0)/dz]$, with g the GRAVITATIONAL ACCELERATION. Under these conditions, the rate of change in height (time: t) of a reference point in the column of FLUID (i.e., infinitesimal parcel of air of cross-sectional area A and height dz) and DENSITY (ρ , with steady-state density ρ_0) are correlated as $d^2 z/dt^2 = -g[(\rho - \rho_0)/\rho]$, where the fluid obeys the hydrostatic equation with respect to pressure P as $dP/dz = -\rho g$, with the pressure as a function of height ($H = RT/g$, GAS constant: $R = 8.3144621(75) \text{ J/Kmol}$). The frequency is named after the two scientists who, independently, introduced the concept: the Swedish scientist Vilho VÄISÄLÄ (1889–1969) and British meteorologist DAVID BRUNT (1886–1965). The full perturbation at a location in the column of fluid is described as $[(D^2/Dt^2) + v_{BV}^2]w + (1/\bar{\rho})(D/Dt)\{[(\partial/\partial z) + (g/v_s^2)]P\} = 0$, where v_s is the speed of SOUND, $(D/Dt) = (\partial/\partial t) + \bar{U} \cdot \nabla \sim (\partial/\partial t) + \bar{u}(\partial/\partial x)$, $\bar{u}$ is the average FLOW velocity in horizontal direction, and w is the vertical displacement VELOCITY (also see HOUGH FUNCTIONS, THERMOSPHERE, and LAMB WAVE).

B-scan

[acoustics] A brightness scan used to describe a specific ULTRASONIC IMAGING technique. Ultrasounds are defined as mechanical SOUND waves having frequencies higher than the audible range. All sounds that can be detected by the human EAR are called audible, thus their frequencies are in the audible range. Audible sound frequencies range from approximately 20 Hz to 20 kHz. During a person's development, the highest detectable frequency progressively decreases. A baby ear can detect sound waves with frequencies as high as 20 kHz; however, an adult can't detect higher than 17 kHz. Moreover, research showed that the fetal ear can detect sounds up to 40 kHz. Many instances showed that animals can use sound waves in more advanced ways than human do. Bats and dolphins are known to be able to detect frequencies up to, respectively, 30 kHz and 158 kHz and showed a fairly high detection RESOLUTION that enables them to navigate and maneuver around obstacles. ULTRASOUND was first characterized in animals and shown to be mostly generated in the larynx. The first ultrasound generating device, Galton whistle, was developed in the 1880s. This device permitted a continuous change in frequency from audible to ultrasonic. This concept is still used for silent dog whistle. Wedge resonators, widely used in the alimentary industry for emulsification, employ a jet of AIR or LIQUID to induce a flexible wedge to flexural OSCILLATION. Another ultrasound GENERATOR used in the alimentation industry is Sirens. It generated ultrasounds by forcing a GAS through punctured rotating disks. Even though the waves generated are not pure sine WAVE, they are widely used for emulsification. The other methods to generate sound waves with very high frequencies are based on material that can change shape upon change in the electromagnetic characteristics of the external environment. Two characterized materials have been shown to have such property: magnets and piezoelectric crystals. MAGNETOSTRICTION is defined as the shape change of an oscillating MAGNET under the action of an external MAGNETIC FIELD. This change of shape is due to the rearrangement of the molecules composing the magnet. Magnetostriction has been first described by JAMES PRESCOTT JOULE (1818–1889) in 1847. Magnetostrictive devices

are extensively used in industry. However, it is difficult to manufacture devices that generate frequencies higher than 500 kHz. The brothers PIERRE CURIE (1859–1906) and PAUL-JACQUES CURIE (1856–1941) discovered piezoelectric crystals in 1880. These crystals have the property to generate electrical charge in their surface when they are under mechanical compression forces. Moreover, these crystals changed their shape when a voltage is applied. The application of an AC voltage with a very high frequency will generate a sound wave with the same frequency. Piezoelectric material can be made from barium titanate and lead zirconate titanate. The most commonly used medical ultrasound devices are based on piezoelectric ceramic. The back layer absorbs back RADIATION thus giving the TRANSDUCER directionality. The piezoelectric ELEMENT is wired to an electric circuit. Actual transducer is controlled by microprocessors and composed of many active ELEMENTS, each consisting of a controlled piezoelectric element. The beam formed will have two zones: near field (Fresnel region) and the far field (Frauhofer region). While the near field is mostly composed of waves traveling in parallel, waves traveling in the far field are divergent. It is possible to use the diffraction properties of sound waves to focus the wave front in a smaller area. An acoustic LENS is generally used for focusing, making the near field a little convergent. This will lead to an increase in the DISTANCE that the front wave will travel before becoming divergent and losing its RESOLUTION.

Physical concepts

Propagation

ACOUSTIC WAVES arise when the particles, of which a medium is composed, are supplied with ENERGY and are driven to vibrate. The VIBRATION of these particles will be transmitted to neighboring molecules due to an energy transfer. This repeated process of particles oscillating and transferring their energy to neighboring particles leading to their subsequent OSCILLATION with the same frequency is characterized as propagation. Even if a SOUND wave can propagate over relatively long distances, the molecules forming the medium stay in the same position. This propagation depends on the physical properties of the medium: v is the velocity of propagation of the sound wave; Y_K is the Young's elastic modulus; and ρ is the density of the medium. A WAVE propagation classical equation relates velocity of propagation, FREQUENCY (ν), and WAVELENGTH (λ): $v = \nu\lambda$. Given that the frequency is source dependent, one can deduce that the wavelength will be dependent on the acoustic properties of the medium.

Reflection and refraction

During its propagation, a sound wave will move through different media. At the interface between two acoustically different media, the sound wave can be significantly affected. Many secondary waves will be generated, one of which is the reflected wave. The ANGLE of REFLECTION is equal to the angle of incidence. The portion of the sound wave that will go through the interface is called the refracted wave. When the interface is smaller than λ , the molecules composing the interface act as point sources and will radiate spherical waves. This effect is called SCATTERING and will be discussed in the next paragraph. The ratio of reflected to refracted sound waves is dependent on the acoustic properties of both media. These properties are characterized by the acoustic impedance which is $Z = \rho v$.

Attenuation

The total energy of a sound wave will progressively decrease due to wave attenuation. Two physical concepts are related to the energy dissipation: The acoustic conductance of a medium will determine its absorption levels. Most biological media are VISCOELASTIC in which a portion of the total MECHANICAL ENERGY will be transformed to heat resulting in a net loss of energy; during the passage of the sound wave through an interface, the sound could be scattered. The scattering implies loss of energy $I = I_0 e^{-\mu x}$, where x is the depth, $\mu = \mu_a + \mu_s$ with the attenuation factor due to absorption (μ_a) and scattering (μ_s).

Mechanical and cavitation effects

First order

The propagation of a WAVE through a media results in MOTION and acceleration of particles (high peak PARTICLE acceleration = $22.452 g$; g is the GRAVITATIONAL ACCELERATION). Damages may result when different portions of the same structure are subjected to different forces so that it is twisted and torn.

Cellular membrane “fatigue” (red blood cell, RBC)

Autolysis of erythrocytes may be the result of repeated exposure to ultrasonically induced hydrodynamics shear stress. Ultrasounds may liquefy thixotropic structure including the mitotic/meiotic spindles.

Cavitation

Oscillatory ACTIVITY of highly compressible bodies such as GAS BUBBLES or “cavities” can be enhanced if the same dose of continuous wave ultrasonic power was administered in the form of relatively long pulses. This will result in violent oscillatory behavior and can disrupt cells such as white BLOOD cells (WBC), platelets, erythrocytes, and epithelial cells and may cause blood coagulation dysfunction.

Macromolecular effects

Several studies have been conducted on different cells’ DNA; the results showed no evidence for single- or double-strand breakage in the DNA. There are no obvious effects of ultrasound waves on enzymes; a CELL is more likely to be destroyed before its enzymatic content is degraded. Ultrasounds have a wide range of application in the medical field, both for diagnostic and for therapeutic purposes. ULTRASONIC IMAGING represents a wide array of use as a primary modality or associated with other medical imaging techniques. Like most of the medical imaging techniques, ultrasonic imaging is mainly a TOMOGRAPHY modality since it visualizes sections of the HUMAN BODY. However, in many of its modalities, a third dimension is integrated which is time. One of the most appealing benefits of ultrasonic imaging is its ability to visualizes soft tissues with a fairly good RESOLUTION. One of the first and most important imaging techniques was X-ray-based imaging. This technique produced very poor resolutions on soft tissues. Hence, ultrasonic techniques represented a major advance in medical imaging by allowing visualization of “non-visualizable” tissues. Ultrasonic imaging uses very fast spreading, and its vulgarization is due to three main reasons: (1) It allows real-time imaging. Ultrasonic imaging added time as a third or fourth dimension. (2) It doesn’t use ionizing RADIATION and has no major side effects. And (3) it provides qualitative as well as quantitative data. Quantitative data are very important for monitoring the progress of a disease under specific therapeutic conditions and doesn’t rely on the subjective analysis of the radiologist.

Resolution

Spatial resolution

It is defined as the ability of a particular system to discriminate between two closely separated scatters. This concept arises from the nature of the detected RADIATION. Spatial resolution is generally referred to LATERAL RESOLUTION, which is the x coordinates of an ULTRASOUND-generated IMAGE and would be directly correlated with the width of the SIGNAL. It is dependent on an $f\#$ factor, which is equal to the focal DISTANCE divided by the APERTURE size. While the aperture size is directly related to the number of active ELEMENTS of the TRANSDUCER (by active elements we mean the number of piezoelectric elements that are controlled by their specific electrical wiring), the focal distance is directly dependent on the depth of the focal area. Many medical imaging research companies have focused on increasing the depth of the focal area without losing resolution and not only resolution at the focal depth but also homogeneity of resolution all along the image. The evolution of transducers has been always correlated with the addition of active elements and the increase in complexity of the MICROPROCESSOR that controls the electrical signals that activate these elements. But increasing active elements is physically constrained and researcher needed another way to enhance resolution that doesn’t involve aperture. This was achieved by creating multiple focal systems.

Homogeneity of resolution

Since each focal zone will have appreciatively equivalent resolutions, a high resolution at all depths is mainly achieved by having a wide APERTURE system. The main limitation of such design is related to the image processing needed to integrate all the images detected of each focal area. Computing limitations and also the need for a fast real-time imaging system limited this approach. Nevertheless, this design has been implemented by many imaging companies and showed great results.

Contrast resolution

It is defined as the ability of a system to discriminate between two acoustically similar scatters. In the early 1940s, ULTRASONIC IMAGING design was thought to be done like X-rays by detecting transmitted ultrasounds. This showed a very low contrast resolution that didn't extract any relevant data. Pulse-echo technique based on analyzing the reflected ultrasounds rather than the transmitted has been proposed and immediately showed much better results. Contrast resolution was much better. The intensity of the reflected SOUND wave depended on the impedance of both media. This demonstrates that even a fairly small difference in acoustic impedances between both media will still generate enough change in intensity to be detected.

Ultrasonic imaging modality

B-mode

It represents a 2D SLICE through a portion of ANATOMY. This modality is widely used in obstetrics to visualize the fetus development in uterus. To acquire the IMAGE, the technician needs to move the TRANSDUCER along the line with a constant velocity. The computer will integrate all the data detected at all the focal distances and will form a 2D image. The classical B-mode will involve the visualization of a sectional plane $z = z_0$ by the linear movement of the transducer in the x direction along that plane. At each time t , a scan will occur, and the image will reflect the sequence of scans starting at t until time $t = t_0 + n\Delta t$, $T = T_0 + n\Delta t$.

Doppler mode

The DOPPLER effect states that changes in the DISTANCE beam–receptor will affect the frequency of the WAVE perceived by the receptor $v = v_0 \left[\frac{v_s}{(v_s - v_o)} \right]$. $f = f_0 * c/(c - v)$, given v is the frequency perceived by the receptor, v_0 is the frequency of the source, v_s is the velocity of SOUND, and v_o is the velocity of the moving beam or receptor. This effect can be used to image movements of acoustic scatters within the HUMAN BODY. Doppler imaging is widely used to visualize the movement of BLOOD. It is used both for peripheral arteries and veins but also for cardiopathologies. Doppler imaging measures blood velocity and detects blood FLOW direction. Two main ways to visualize Doppler imaging are as follows: A COLOR code imaging coupled with a B-mode shows the blood velocity and is very useful to detect regurgitation or abnormal blood flows. A plot of blood velocity along a peripheral artery can detect stenosis and other pathologies related to vascular degeneration.

Harmonic imaging

Concept

Superficial tissue structure, for example, SKIN, fat, and MUSCLE, produces pulse distortion and aberration. The sound wave emitted by the TRANSDUCER is a perfect sine wave; however, the reflected wave that will be detected by the transducer is a much distorted wave. This WAVE includes not only the FUNDAMENTAL WAVE but also many other waves, one of which is the second harmonic wave whose frequency is twice the frequency of the emitted wave. During the year 1980, Muir and Carstensen first demonstrated the conventional imaging array that produced significant nonlinear effects. Many research projects have been done to explore the nonlinear effects of ultrasounds. Today, major medical ULTRASOUND companies sell harmonic imaging systems based on conventional array/system technology. A better understanding of harmonic waves will push toward a new generation of transducers and systems that are more specific to harmonics and will lead to better RESOLUTION. Acoustic nonlinearity is due to the pressure density (constitutive) behavior, meaning that high pressures are correlated with higher densities and lead to higher SOUND propagation velocities. In contrast, low pressures are correlated with lower densities and lead to lower propagation velocities. Most of the nonlinear characteristics of ultrasounds have been studied through computer simulations and based on mathematical modeling. One of the most recent mathematical models is the quasilinear model. A nonlinear equation, which describes the propagation sounds in soft tissues, is defined by the pressure fluctuations ($P(\vec{r}, t)$) as a function of location ($\vec{r}$) and time: $\nabla^2 P(\vec{r}, t) - (1/v^2) \left[\partial^2 P(\vec{r}, t) / \partial t^2 \right] + LP(\vec{r}, t) = \epsilon \left[\partial^2 P^2(\vec{r}, t) / \partial t^2 \right]$, here v is the speed of sound, L is a LINEAR OPERATOR that accounts for loss, and ϵ is a small parameter and is very

small in soft tissue (10^{-3}). The QUASILINEAR approximation is based on a perturbation of the first equation: $P(\vec{r}, t) = P_1(\vec{r}, t) + \epsilon P_2(\vec{r}, t) + O(\epsilon^2)$. Thus, $\nabla^2 P_1(\vec{r}, t) - (1/v^2)[\partial^2 P_1(\vec{r}, t)/\partial t^2] + LP_1(\vec{r}, t) = 0$ and $\nabla^2 P_2(\vec{r}, t) - (1/v^2)[\partial^2 P_2(\vec{r}, t)/\partial t^2] + LP_2(\vec{r}, t) = \epsilon[\partial^2 P_1^2(\vec{r}, t)/\partial t^2]$, where P_1 represents the fundamental field and P_2 is the second harmonic wave, assuming that $\epsilon^2 P_1 = O(\epsilon^2)$.

B

Generation

In addition of being naturally generated, second harmonic waves can be generated by using contrast agents. Contrast agent will lead to a much homogenous second harmonic wave with a higher intensity. Contrast agents are still under extensive research. Properties of an ideal contrast agent are as follows: it should be nontoxic, easily eliminated, administered intravenously, pass easily through microcirculation, physically stable, and acoustically responsive: stable harmonics.

Advantages

Harmonic signal is narrower and have less side lobes. This will significantly increase the spatial resolution. Since the harmonic waves are generated inside the tissue, they will travel only once through the tissue to reach the transducer and thus will be less deformed. Harmonic imaging has been proven to increase resolution and to enable more enhanced diagnostic capabilities (see Figure B.65).

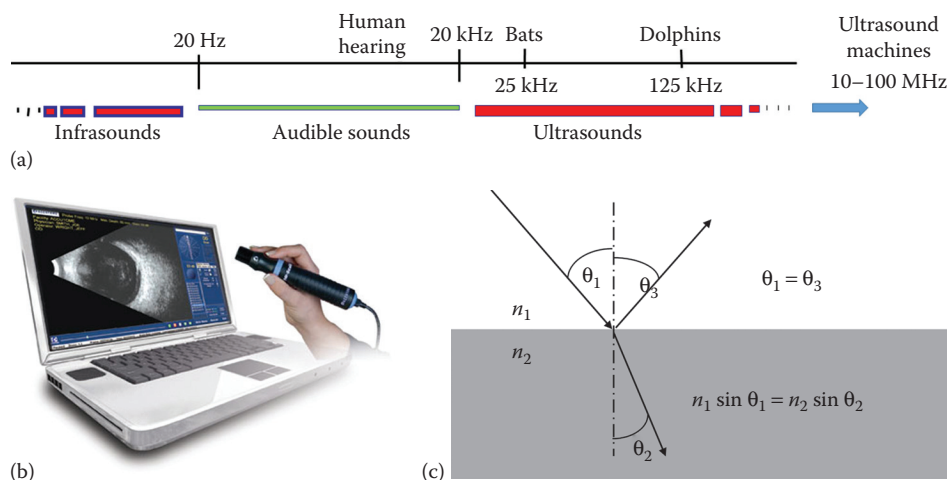


Figure B.65 (a) B-scan sound spectrum background, (b) portable ultrasound B-scan probe and signal processing and display unit from Optos, and (c) representation of interface between two media (e.g., air [above] and water [below]).

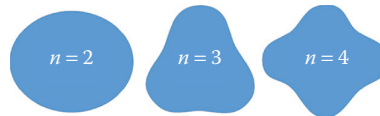
Bubble

[mechanics, thermodynamics] Volume of VAPOR or GAS surrounded by a LIQUID surface, respectively, flexible solid surface of a medium with SURFACE TENSION, either as a shell in a gaseous medium or alternatively confined within a liquid medium. The bubble is formed under equilibrium forces of surface TENSION ($F_s = 2\pi r\sigma_s$) and pressure force applied to the opposing hemispheres ($F_p = PA = P\pi r^2$, where A is the cross-sectional area and r is the radius of the spherical bubble): $\sigma_s = Pr/2 = (\partial U/\partial \alpha_A)_{S,V,n_i} = (\partial E_H/\partial \alpha_A)_{S,V,n_i}$ (U is the internal ENERGY of the medium at the surface, α_A is an infinitesimal surface area, E_H is the Helmholtz free energy, S is the entropy, V is the volume, and n is the quantity of constituent i). Bubble VIBRATION is the deformation of a bubble under the

influence of inherent or external conditions. The forces on the bubble are governed by the Bond number: $Bo = \text{oscillation force/surface tension} = (kr)^2 \varphi_A^2 (\rho_o/\rho_i)$ ($k = 2\pi/\lambda$ is the wave number for wavelength λ and φ_A is the AMPLITUDE of the VELOCITY POTENTIAL for the surface), the REYNOLDS NUMBER: $Re = \text{inertial force/viscous force}$, and the Weber number: $We = \text{inertial force/surface tension}$. Many different deformations are possible and for convenience only a radial EXPANSION/collapse is described. A free OSCILLATION of a bubble (or droplet for that MATTER) has several harmonic frequencies ($\nu = \omega/2\pi$; ω the ANGULAR FREQUENCY) (order n) defined by $\omega_n^2 = n(n+1)(n-1)(n+2)/r^3 [n\rho_o + (n+1)\rho_i]$, where ρ_o is the density of the outer FLUID (or the density of the “SKIN” of the bubble) and ρ_i is the density of the inner fluid. Forced bubble oscillations can be induced by acoustic modulations and are referred to as initiated by the primary Bjerknes force. Conservation of momentum provides the outline for the volumetric extension (with velocity $\vec{v}$) as $(\partial \vec{v} / \partial t) + \vec{v} \cdot \nabla \vec{v} = -(1/\rho) \nabla P + (1/\rho) \nabla \cdot \vec{\sigma}_s + (1/\rho) \vec{F}_B + (1/\rho) \vec{F}_s + A(2\pi\nu)^2 \cos(2\pi\nu t)$ with $\vec{\sigma}_s = \eta_{\text{visc}} (\nabla \vec{v} + [\nabla \vec{v}]^T)$ for NEWTONIAN FLUID with VISCOSITY η_{visc} , the shear stress TENSOR; external forces $\vec{F}_B$; and oscillating resonant force $A(2\pi\nu)^2 \cos(2\pi\nu t)$. Generally, the oscillations will be nonuniform (chaotic), abandoning the perfect spherical design. The bubble shape design can be classified under Legendre shapes, based on the LEGENDRE POLYNOMIAL series extension for the radius $r = (r_0/2) + \sum_{i=0}^{\infty} A_i(t) p_i(\cos\theta)$, where $p_i(\cos\theta)$ is the oscillatory harmonic of order i with AMPLITUDE $A_i(t)$ (also see CAVITATION and LAPLACE LAW) (see Figure B.66).



(a)



(b)

Figure B.66 Illustrations of bubble. (a,b) Examples of several Legendre bubble shape configurations.

Bubble chamber

[general, nuclear] A sealed vessel designed to provide a visual impression of the trajectory of an electrically charged PARTICLE. The chamber is either filled with a saturated GAS (i.e., cloud chamber) or superheated transparent LIQUID. On the passage of the ION, the interaction with the medium generates a trail of condensation droplets or BUBBLES in a liquid. The application of an external electric or MAGNETIC FIELD provides the means of “steering” the particle in MOTION (acting as a current) under the influence of Lorentz force. The first cloud chamber was constructed in 1912 by CHARLES THOMSON REES WILSON (1869–1959)

from Scotland, UK, for which he received the Nobel Prize in Physics in 1927 (shared with ARTHUR HOLLY COMPTON [1892–1962]). The bubble chamber evolved later as introduced by DONALD ARTHUR GLASER (1926–2013) from the United States in 1952 (for which he received the Nobel Prize in Physics in 1960) (see [Figure B.67](#)).

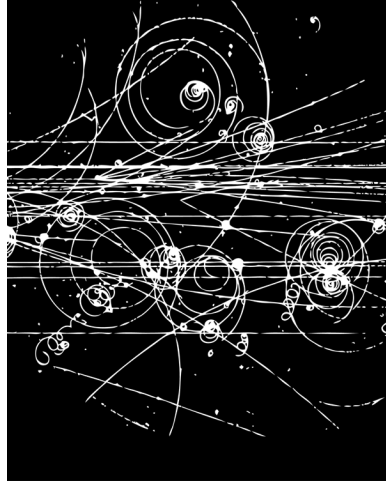


Figure B.67 The trajectory of a charged particles exposed to a magnetic field passing through a liquid, forming a bubble track.

Buckminster Fuller, Richard (1895–1983)

[general, mechanics] An engineer, inventor, and architect from the United States. Richard Buckminster Fuller designed a multi-point interconnect that can support a “hollow structure” with minimal use of material while providing maximal strength (see [Figure B.68](#)).



Figure B.68 Richard Buckminster Fuller (1895–1983).

Buckyball

[chemical, general, mechanics] Geometric configuration described by RICHARD BUCKMINSTER FULLER (1895–1983), also known as a geodesic dome. The buckyball has surprising mechanical stability and the concept is also applied to towers for the inherent strength and reduced requirements for construction materials. In chemistry there are several molecular configurations that use the atomic interconnects) covalent bonds) forming a “spherical” structure, for instance Buckminsterfullerene, a fullerene molecule with the formula C₆₀, which displays a fused-ring structure, resembling a cage or the outline of a soccer ball the C₆₀ structure has 60 carbon atoms that are arranged in twenty hexagons and twelve pentagons. The carbon ATOM at each vertex provides the structural integrity of each polygon. Buckminsterfullerene was discovered in 1985 and is named after the architect that provided the mechanical concept in the early 1940s out of aluminum tubes with 5-point JOINTS and covered by a plastic-vinyl skin, in icosahedron (polyhedron with 20 triangular faces, 30 edges and 12 vertices) configuration (see [Figure B.69](#)).



Figure B.69 The “buckyball” in chemistry and engineering: Biosphere dome.

Buffer, Chemical

[chemical] Solution mixture selection with the primary purpose to reduce the fluctuations in HYDRO-GEN concentration as a result of interactions with other chemicals. In general, the buffered solution has a relatively stable pH. The stable pH guarantees a controlled environment to study the interaction with the hydrogen ION (i.e., H⁺). The buffer results from an interactive molecular SOLUTE coexistence, where the constituents are capable to transfer protons rapidly and reversibly. Generally, the buffer is a mixture of ingredients that maintains a chemical equilibrium by means of a constant conversion of MOLECULES to IONS and in reverse. In this manner, the CHEMICAL POTENTIAL of the respective constituents is directly correlated with the chemical potential of all the chemical species in the respective chemical reactions. The premise of the solution is to make it impervious to REDOX POTENTIAL of the ingredients, TEMPERATURE, ACIDITY changes due to variations in external conditions as well as PRESSURE. The most common type of chemical reactions is dominated by the hydronium ion (H₃O⁺) as a source for PROTONS (i.e., H⁺), that is, the ACID–base buffer. The equilibrium condition in the chemical reaction between the acid concentration ([AH⁺]) and base concentration ([B]) with respect to the conjugated base in solution (e.g., AH⁺ + H₂O ⇌ B + H₃O⁺) is defined by an equilibrium constant or dissociation constant $K^D = \frac{[\text{H}_3\text{O}^+][\text{B}]}{[\text{AH}^+][\text{H}_2\text{O}]}$. The acidity of the buffer, defined as the concentration of the buffer component ([H₃O⁺]), is a direct function of the dissociation constant and the concentration of the added acid only ([AH⁺]), not the acidity of the acid (*Note*: hydrochloric acid has a much lower pH than vinegar), as expressed by $[\text{H}_3\text{O}^+] \cong \sqrt{K^D [\text{AH}^+]}$.

Buffer, Electronical

[electronics] An electronic circuit designed to minimize the **AMPLITUDE** ($\mathcal{A}$) and **FREQUENCY** (ν) content of the **SIGNAL** transfer between a high **IMPEDANCE** (Z) source and a low impedance **LOAD**. Generally, the buffer consists of an amplifier with unit **AMPLIFICATION** ($M_{\mathcal{A}} = 1$), wired in a circuit to provide infinite input impedance ($Z_{\text{in}} = \infty$) and zero output impedance ($Z_{\text{out}} = 0$). In this manner, the source is not subjected to an **ENERGY** drain, since in theory there is no current emerging from the source.

Bulk modulus (B)

[dynamics, mechanics] A deformation parameter based on the elastic potential defined as the unidirectional stress (σ_n) per unit strain (ϵ_n) where the transverse modes are not confined (i.e., ϵ_2 and ϵ_3 are allowed to change): $B = -V(dV/dP)$, where V is the volume of the medium and P is the pressure.

Bulk modulus (B_M)

[general, mechanics] The measure of compressibility of a **VOLUME** (V) of substance, defined as the ratio of the change in stress $\Delta F/A$ over the fractional change in volume when subjected to a uniform compression force on all surfaces with constant area simultaneously $B_M = (\Delta F/A)/(\Delta V/V)$, for convenience the substance will be a cube. For liquids and solids, the bulk modulus will be constant in approximation; however, for a **GAS** the bulk modulus will be a function of the applied pressure.

Bullialdus, Ismaël (1605–1694)

[general] An astronomer and scientist from France. Ismaël Bullialdus provided supporting evidence for the ideas posted by **NICOLAUS COPERNICUS** (1473–1543), **GALILEO GALILEI** (1564–1642), and **JOHANNES KEPLER** (1571–1630). Supposedly, he postulated the inverse square law for gravitational attraction. Additionally, he presumably hypothesized that the **PLANETARY ORBITS** should be ellipses, not circular (Bullialdus' conical hypothesis) (see [Figure B.70](#)).

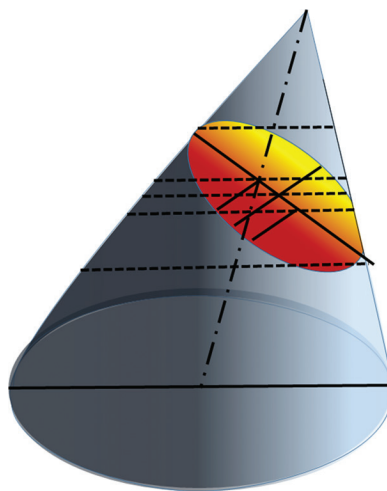


Figure B.70 The Bullialdus' conical hypothesis.

Bunsen, Robert Wilhelm Eberhard (1811–1899)

[general, optics] A physicist and chemist from Germany. In collaboration with **GUSTAV ROBERT KIRCHHOFF** (1824–1887), they discovered that the spectral absorption of atmospheric constituents provided specific patterns, representative of the **ENERGY** transitions. These observations were used to explain

the **FRAUNHOFER LINES** in the solar spectrum, discovered by **JOSEPH VON FRAUNHOFER** (1787–1826) in 1814. Bunsen also investigated the spectral emission lines of several **ELEMENTS** under elevated temperatures and discovered caesium (1860) and rubidium (1861). He also devised the “Bunsen burner” for use in his chemical experimentation, still widely used up to this day for heating beakers and test tubes with chemical reagents (see [Figure B.71](#)).



Figure B.71 (a) Robert Wilhelm Eberhard Bunsen (1811–1899). (b) Bunsen burner, used in most general laboratory experiments.

Bunsen–Roscoe rule

[chemical, thermodynamics] Based on **CONSERVATION OF ENERGY** constraints, it can be shown that the **MAGNITUDE** of the product resulting from a **PHOTOCHEMICAL REACTION** is directly proportional to the administered total dose of **ENERGY**, irrespective of the exposure time over which the energy dose is delivered. It is derived by **ROBERT WILHELM EBERHARD BUNSEN** (1811–1899) and **HENRY ENFIELD ROSCOE** (1833–1915).

Buoyancy

[fluid dynamics, general] [ref. mechanics] (syn.: Float, Archimedes' principle) {use: biomedical, statics} An object submerged in a **FLUID** medium (**LIQUID** or **GAS**) will experience an apparent weight that is its own weight reduced by the weight of the volume of the displaced fluid. This phenomenon was first described by the Greek physicist **ARCHIMEDES** (287–212 BC) in approximately 214 BC, while taking a bath. **SURFACE TENSION** will affect the total outcome of the apparent weight. The Archimedes principle can be used to derive the **DENSITY** (ρ) of an unknown object. Additionally, the relative composition of components can be established, such as the amount of body fat or the gold content. The upward (buoyancy-) force is defined as $F_b = \rho_f V_i g$, where V_i is the volume and ρ_f is the density of the displaced fluid. Technically, the forces are

vectors, and hence, a negative sign means against the direction of GRAVITATIONAL ACCELERATION, also known as Archimedes' principle (see [Figure B.72](#)).



Figure B.72 Buoyancy principle. Row-boat floating due to displaced water providing buoyant upward force.

Buys Ballot, Christophorus Henricus Diedericus (1817–1890)

[fluid dynamics, general, geophysics, meteorology] A Dutch physicist, chemist, mathematician, and meteorologist known as Buys Ballot, after whom the correlation between the direction of the wind and the horizontal pressure-gradient *lines* was named, specified by hemisphere as the BUYS-BALLOT LAW. For his work on geophysics and natural phenomena, he was appointed as the first director of the newly established Royal Dutch Meteorological Institute (KNMI: Koninklijk Nederlands Meteorologisch Instituut), a research institute for weather phenomena, still in use as the official Dutch weather observatory and weather forecasting facility. He observed that the airflow around low-pressure systems in the northern hemisphere is counterclockwise and clockwise around high-pressure systems. Additional observations made by Buys Ballot involve the banking (rising higher on one side) of the airflow to the right in the northern hemisphere and to the left in the southern hemisphere under a force described under CORIOLIS FORCE. The Coriolis force described the MOTION influenced by an object in rotation. Buys Ballot made the first steps to the formation of the World Meteorological Organization (WMO) by the formation of the International Meteorological Committee in 1873 (see [Figure B.73](#)).



Figure B.73 Christophorus Henricus Diedericus Buys Ballot (1817–1890), drawing made in 1857.

Buys Ballot law

[fluid dynamics, general, geophysics, meteorology] In atmospheric sciences, the AIR FLOW will travel around a high (or low) pressure system in counterclockwise on the northern hemisphere and in clockwise direction on the southern hemisphere. This can be interpreted by a person standing on the northern hemisphere with his/her back toward the wind that the low pressure area will be on the left hand side. This concept was introduced by CHRISTOPHORUS HENRICUS DIEDERICUS BUYS BALLOT (1817–1890) in 1857.



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Cadherins

[biomedical, chemical] In biology there is cell-to-cell interaction, which can be divided into four types of receptors: cadherins, selectins, INTEGRINS, and IMMUNOGLOBULIN SUPERFAMILY. Cadherins rely on the abundance of Ca^{2+} ions to provide a platform for temporary ADHESION. The adhesion is homotype, using the cadherin molecules to bind to each other spanning the extracellular space.

Cadmium [Cd]

[nuclear] ELEMENT: $^{112}_{48}\text{Cd}$. Semiconductor material.

Caisson disease

[biomedical, fluid dynamics, general] Decompression disease, formation of embolisms resulting from the release of GAS BUBBLES from tissue into the bloodstream, primarily nitrogen, when the external pressure applied to the body is reduced too quickly. This phenomenon is connected to OSMOTIC PRESSURE, the partial pressure associated with dissolved gases, which can occur during scuba-diving expeditions on return to the sea level, while surfacing too rapidly. Originally the disease was associated with the exodus from a closed compartment, a caisson (when returning from underwater efforts while enclosed in the caisson under compressed AIR). One example is the use of caissons while working on the New York Brooklyn Bridge in the 1870s. The compressed air was necessary to compensate for the external hydrostatic pressure applied by the resting water column, where each 10 m of water corresponds to approximately 1 atmosphere, or 101.325 kPa, also called “the bends” or “divers disease” (see [Figure C.1](#)).



Figure C.1 Decompression chamber used to mitigate and treat decompression sickness after deep-sea diving, used by the United States Navy. (Courtesy of Jayme Pastoric, Mass Communication Specialist 2nd Class, US Navy.)

Calcification

[atomic, biomedical] The ADHESION of calcium to surfaces of implanted devices in biological organisms. Another form of calcification is in the formation of plaques in the lumen of BLOOD vessels, making it tougher and harder than fatty plaques. Other mineralization effects of calcium are in diseased tissues, causing the biological material to become more rigid and hence fragile for tearing and fracture. During osteoporosis, bone calcium level decreases due to metabolic inequilibrium and a deficiency in the supply chain, primarily due to eating habits. Calcium deposition on HEART valves gradually evolves into hardening of the valves, resulting in a diminished efficacy of the PUMP function due to regurgitation and seepage (see [Figure C.2](#)).



Figure C.2 Calcification of a water heater element due to “hard water” with calcium content.

Calcium [Ca]

[atomic, biomedical] ELEMENT used in the formation of bone and teeth as well as in the communication between cells ($^{40}_{20}\text{Ca}$). Biological CELL have special calcium channels that carry the calcium ION (Ca^{2+}) charges for the creation of an ACTION POTENTIAL in combination with sodium and potassium ions. The calcium ion electropotential is described by the NERNST EQUATION. The calcium ions and atoms also play a role in the Gibbs free ENERGY calculations for biological cells. Calcium is a major catalyst in SKELETAL MUSCLE contraction. Another implication of calcium is in the formation of plaque in the BLOOD vessels. About 1% of calcium is dissolved in blood, and the remaining 99% is in cellular structures and muscular processes.

Californium [$^{251}_{98}\text{Cf}$]

[nuclear] Radioactive unstable ELEMENT, classified as a METAL in the element category of Actinide with a half-life of 898 years. Californium was synthesized at the University of California, Berkeley, in the 1950. The metal is artificially generated as a result of colliding CURIUM [$^{247}_{96}\text{Cu}$] with ALPHA PARTICLES [$^4_2\text{He}^{2+}$]. Other isotopes have a much shorter half-life with aggressive RADIATION. The disintegration process of Californium generates NEUTRON emission and also produces ALPHA DECAY, which results in the production of isotopes of Curium. Californium possesses a simple hexagonal crystal structure.

Calipers

[computational, general] Measuring device that is designed for analog measurements of size with relative accuracy, generally in the order of $0.01 - 0.05$ mm. In geometry this refers to a mechanism of calculating the configuration of a polygon, expressed by its ANTIPODAL POINTS forming pairs and vertices. The computational rotating caliper respectively aligns a “caliper line” with the edges of a polygon, thus defining the corners or antipodal pairs while successively moving the caliper line around the polygon. Also used to describe the disk-break pressure clamp for the wheels of an automobile or motorcycle, also called “calliper” (see [Figure C.3](#)).

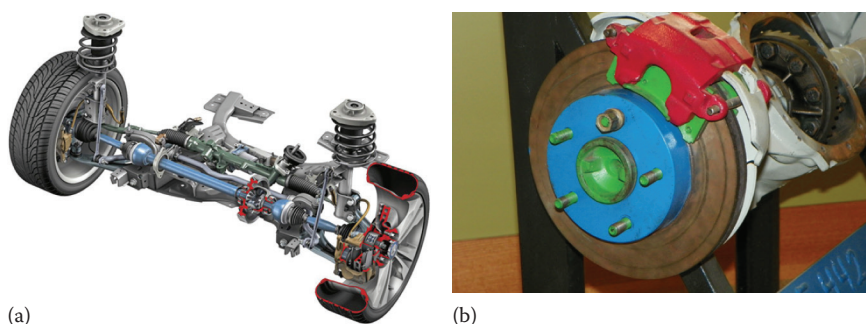


Figure C.3 (a) Brake calipers on a Mercedes automobile front axle and (b) close up of disk brake calipers. (Courtesy of Daimler AG.)

Callen, Herbert Babar (1919–1993)

[computational, thermodynamics] Physicist from the United States who made significant contributions to the theoretical formulation of thermodynamic concepts.

Calley, John (1663–1717)

[energy, mechanics] Physicist and engineer from the United Kingdom, coinventor of the modern concept of the steam ENGINE in 1712 with THOMAS NEWCOMEN (1663–1729). The other, more well-known, inventor related to the stem engine is JAMES WATT (1736–1819).

Caloric

[general, thermodynamics] Hypothetical concept of heat as a FLUID, named CALORIC, introduced in 1809 by Horatio Gates Spafford (1778–1832) in his *General Geography, and Rudiments of Useful Knowledge: In Nine Sections [Illustrated with an Elegant Improved Plate of the Solar System. A Map of the World. A Map of the United States]*, propounds the idea of heat being a subsystem of MATTER that is indestructible and self-repellent is incorrect. This concept was intended to replace KINETIC THEORY, the idea that atomic/molecular MOTION is the foundation for the transfer of heat and was not introduced until COUNT RUMFORD (BENJAMIN THOMPSON

[1753–1814]) described the equivalence of work and rising temperature in 1798. However, the principle of heat and “MOLECULAR MOTION” was introduced in a rudimentary form by PLATO (427–347 BC) and later reaffirmed by GALILEO GALILEI (1564–1642) (see [Figure C.4](#)).



Figure C.4 Horatio Gates Spafford (1778–1832), thermodynamics engineer who introduced the caloric concept in 1809.

Caloric theory

[general, thermodynamics] The concept of a physical medium that transfers ENERGY, also referred to as theory of CALORIC. The fluidic medium involved in the energy transfer in question was named “caloric,” supposedly indestructible (*see* CONSERVATION OF ENERGY) and self-repellent (this statement comes back in a different format with respect to a concept loosely connected to energy: ENTROPY).

Caloric value

[general, thermodynamics] Concept of HEAT TRANSFER introduced by Professor JOSEPH BLACK (1728–1799) in 1760. This concept is based on Black’s theoretical interpretation of the ENERGY transfer between two systems; he also introduced the concept and unit of Calorie into the process of raising the temperature of a body.

Calorie (cal)

[biomedical, general, thermodynamics] The amount of HEAT necessary to raise the temperature of 1 g of water by 1°C (from 14.5°C to 15.5°C) under ATMOSPHERIC PRESSURE ($1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2 = 1.013 \times 10^5 \text{ Pa}$). Abbreviated unit: cal = 4.186 J; kilocalorie is expressed as Cal (*also see* HEAT CAPACITY).

Calorimeter

[general, thermodynamics] Device used to determine the CALORIC VALUE of a substance, insulated to avoid exchange of HEAT with the exterior media (see Figure C.5).

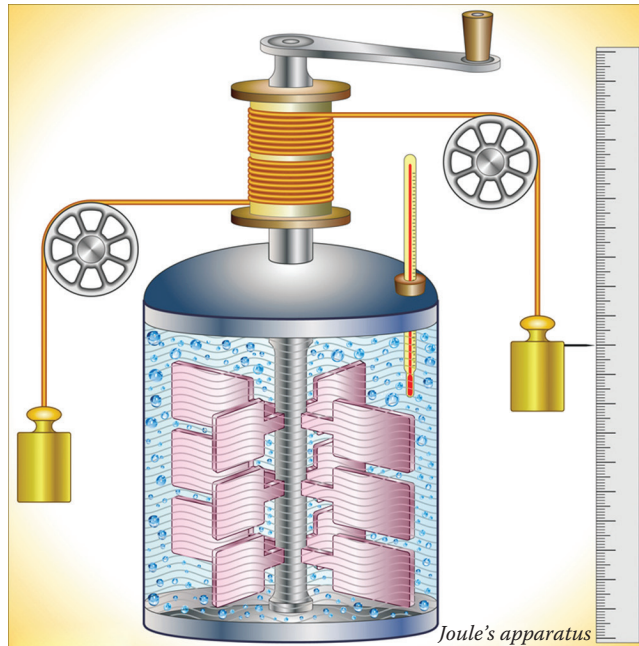


Figure C.5 A calorimeter.

Calorimetry

[biomedical, energy, thermodynamics] Indication of the interchange of ENERGY: energy loss by hot object = energy gain by colder object. Additionally, in biological applications calorimetry describes the process of converting one form of energy, specifically the CALORIC VALUE of fuel (i.e., food) involved in METABOLIC activity, for example, body temperature, CELL division, and MUSCLE action. In general, thermodynamic applications calorimetry is an indication of the energy consumption of pyrotechnic activity, combustion as well as PHASE transitions (e.g., melting, vaporization, and general heating and cooling, such as the Carnot process). The process of melting and vaporization introduces the LATENT HEAT OF FUSION and the LATENT HEAT OF VAPORIZATION.

Calpain

[biomedical, chemical] Protein in the proteolytic enzyme family, calcium-dependent with symmetric peptidase core. This type of protein is found in the connective tissues of the brain, EYE LENS, and SKELETAL MUSCLE. The proteolytic nature identifies the use of peptide bonds for binding to amino acids, forming a POLYPEPTIDE chain.

Calvin cycle

[biomedical, chemical, thermodynamics] Photosynthetic carbon reaction in biological cellular METABOLISM ENERGY transfer. The “dark reactions” pathway in PHOTOSYNTHESIS. In this chemical reaction pathway, the free energy obtained from cleaving phosphor bonds within ATP is applied to fix CO₂ and chemically reduce, in order to form CARBOHYDRATE. The enzymes and their intermediates involved in the Calvin cycle

are located in the cellular chloroplast stroma. The stroma forms a compartment that is equivalent to the mitochondrial matrix. This metabolic cycle was characterized by Melvin Ellis Calvin (1911–1997), with the support from James Bassham (1922–2012) and Andrew Benson (1917–), for which Melvin Calvin received the Nobel Prize in Chemistry in 1961 (see [Figure C.6](#)).

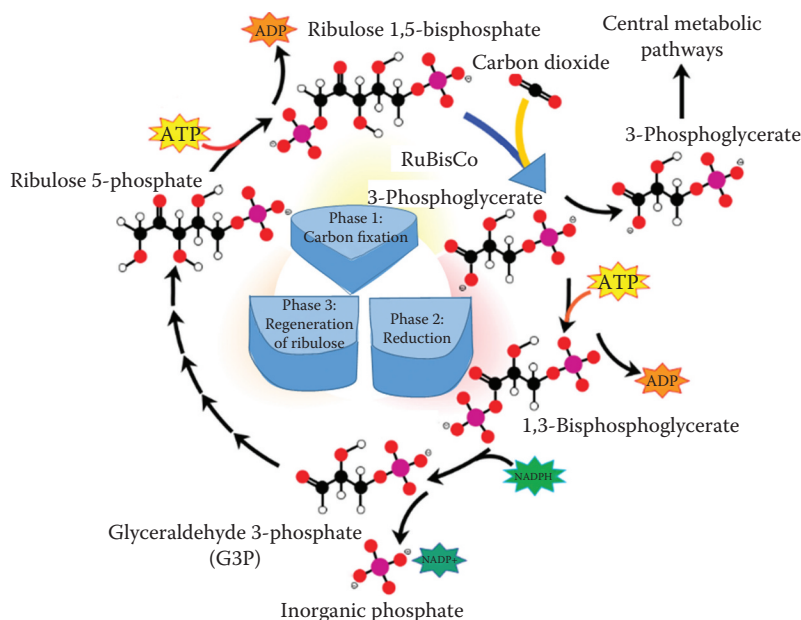


Figure C.6 The Calvin cycle. (Courtesy of Mike Jones.)

Camber

[fluid dynamics] The asymmetric surface contours of the upper and lower surfaces of an AEROFOIL. Because of a difference in camber between the upper and lower surface, the air-flow velocity over the top will be greater than under the bottom, providing a pressure difference between the top (lower) and the bottom (higher) based on the Bernoulli equation. The definition of camber ensures the maximum LIFT COEFFICIENT for the object in-flight. This principle is defined numerically by the line connecting the front and the tail end of the WING described by the CAMBER LINE ($Z(x)$) with a path length for the AIR to travel: for the upper portion, $Z_{\text{up}}(x) = Z(x) + (1/2)T(x)$, where $T(x)$ is the “thickness function,” which varies with location (x) from front to rear, and for the bottom of the aerofoil, $Z_{\text{low}}(x) = Z(x) - (1/2)T(x)$. The thickness curve can be of any formulations, for instance $T(x) = -(t_r/0.2) \left[-a_1x^{1/2} + b_1x + c_1x^2 - (c_1 - 1)x^3 + d_1x^4 \right]$, where t_r is the thickness ratio. In supersonic design the camber can also be negative (see [Figure C.7](#)).



Figure C.7 Camber of model plane wing on profile.

Camber line

[fluid dynamics] On an AEROFOIL the camber line indicates the partition line separating the upper and lower curved surfaces of the WING. The CAMBER of the respected curved surfaces provide the in-flight LIFT. An aerofoil that curves upward at the tail end of the wing has a chamber line that curves up as well. An example of a curved chamber line is $Z(x) = D_2 [b_2x - c_2x^2 + (c_2 - 1)x^3]$, which varies with location (x) from front to rear and a and b are constants.

Camera

[general, optics] Optical instrument used for collecting still images or moving footage on a SOLID-STATE or digital format recording mechanism. The early cameras used photographic film to record single still images for still PHOTOGRAPHY and a sequence of still images in high frame-rate acquisition for movies. Later photography relied on a CHARGE-COUPLED DEVICE (CCD) array to record matrix ELEMENTS of grayscale or red–green–blue (RGB) values in electronic format with a variable dynamic range and in a range of PIXEL magnitudes. The camera has a simple or complex set of lenses (or only a single LENS, for low-end quality imaging) that correct for distortions and COLOR aberrations resulting from diffraction. The early mode solid-state camera used silver-chloride-coated plastic strips for the photographic effect. The silver chloride oxidizes and is later processed by chemical interactions to form a fixed chemical structure that covers the surface of the PHOTOGRAPHIC PLATE. This mechanism will result in a negative IMAGE, since more light will result in an increase of the OXIDATION process, making the chemical darken respectively. The final process in the solid-state design requires the production of a print on a paper that is chemically treated to respond to the exposure to light in a similar manner, this presents the hues in the same relative distribution as when observed in real life. The image formation system uses a thin lens combination with a range of lenses with various optical configurations to provide wide-angle or zoom image capture possibilities. The image formation relies on magnification for both capture and hard-copy reproduction (see [Figure C.8](#)).



(a)



(b)

Figure C.8 (a) Picture of an old-fashioned Kodak camera. (b) Picture of a new age digital camera.

Camera obscura

[general, optics] Imaging device using a pinhole as the Fourier LENS that provides an inverted spatial DECONVOLUTION of a light pattern generated by a source distribution on a screen or PHOTOGRAPHIC PLATE. The IMAGE has an optimal RESOLUTION depending on the diameter of the pinhole depending on the Rayleigh diffraction mechanism and the WAVEFRONT. The image formation is based on the PARAXIAL IMAGE FORMATION approach. The pinhole image formation was first described by ARISTOTLE (384–322 BC) (see Figure C.9).

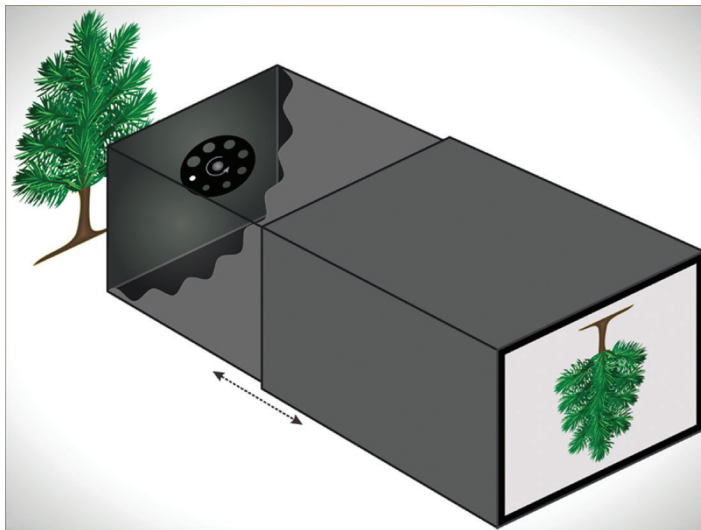


Figure C.9 Camera obscura.

Canal rays

[nuclear] In gas-filled tube with ANODE and CATHODE this represents the ions released from the anode, and are called anode ray or canal ray. The POSITIVE IONS migrate toward the anode under the applied electric field. The canal rays migrate in the opposite direction from the cathode (electron) ray. The exact nature of the positive canal ray depends on the GAS and hence the ions formed by surrendering any number of electrons at the positive anode. The discovery of the positive PARTICLE stream was made in 1886 by EUGEN GOLDSTEIN (1850–1930).

Canal theory of the tides

[fluid dynamics, geophysics] Canals have a specific tidal FLOW pattern due to FORCED OSCILLATION induced by the ebb and flood conditions. In some places the riverbed topography can create spectacular flow conditions, primarily resulting from the changes in propagation velocity with respect to long versus short waves.

One example is the surf in the Kampar River in Sumatra and another is in Girdwood, Alaska, with a succession of TIDAL WAVES running for 8 km along the riverbed (see [Figure C.10](#)).



Figure C.10 Canal wave examples. (a) Sumatra, Indonesia. The “Seven Ghosts” wave can have a crest of up to 3 m and travels the distance of the Kampar River for up to 50 km, (b) Sumatra; tidal bore, (c) Kampar River; Bono wave, and (d) Alaska. (Courtesy of Bono Surf.)

Canal waves

[fluid dynamics] *See* TIDAL WAVES.

Cancellous bone

[biomedical] Spongy bone with internal structure similar to a honeycomb (“trabecular”) found for instance in ball JOINTS, pelvis (ilium), skull (cranium), and the scapula (i.e., shoulder blade). Cancellous bone constitutes approximately 20% of the bone structure in the human ANATOMY. The Young’s modulus for cancellous bone is $E_Y = 1$ GPa, whereas the CORTICAL BONE found in the skeletal structure such as the tibia has a Young’s modulus of $E_Y = 18$ GPa. Cancellous bone is rich in bone marrow and is an essential supplier of red BLOOD cells.

Canonical ensemble

[computational, thermodynamics] A thermodynamic arrangement with two components: one component is a system at constant temperature and the second system a heating bath to maintain the temperature in system 1.

The ensemble will still have fluctuations in ENERGY (E). The ensemble consists of a fixed number of particles (N), a constant volume (V), and at constant temperature (T), which defines the CANONICAL ENSEMBLE at $N; V; T$. Note that the temperature is related to ENTROPY (S) as $(1/T) = (\partial S / \partial E)$. The distribution of the Hamiltonian (H_s) and the Entropy (S_s) for the ensemble is defined by a normalized BOLTZMANN DISTRIBUTION, or canonical energy distribution ($\rho_c(\{q_i\}, \{p_i\})$, where $\{q_i\}, \{p_i\}$ represent the DEGREES OF FREEDOM for the system) as

$$\rho_c(\{q_i\}, \{p_i\}) = \left[\frac{1}{\int \prod_{i=1}^{3N} \exp(H_s(\{q_i\}, \{p_i\}) / k_b T)} \right] \exp - [H_s(\{q_i\}, \{p_i\}) / k_b T]$$

where $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg} / \text{s}^2 \text{ K}$ is the Boltzmann coefficient.

Canonical transform

[computational] When compared to Hamiltonian transform (with operator H_{tr}) and Lagrangian formulation, the canonical transform (with operator C_{tr}) implicitly does not have time as a parameter. The canonical transform requires an additional factor to conform to a Hamiltonian expressed as $H_{tr} = C_{tr} + (\partial F_{tr} / \partial t)$, where F_{tr} is a generating or transform function.

Canonical turbulent boundary layer

[computational, fluid dynamics, geophysics] Elaborating on the work by LUDWIG PRANDTL (1875–1953) on boundary layers published in 1904, the features in a zero pressure gradient in the streamlined high Reynolds number FLOW of an incompressible medium are described in a PIPE where the flow phenomena are not affected by WALL CURVATURE or SURFACE ROUGHNESS. In the formation of the canonical turbulent boundary layer the conditions also mandate that there are no obstruction upstream. The high REYNOLDS NUMBER ($Re > 350 - 730$ range) in the shear layer will be the instigator for canonical condition. One way of achieving the conditions for canonical turbulent boundary layer flow are through “shock” flow, jets of high velocity.

Capacitance (C)

[biomedical, electronics, general] Electrical capacitance [C] specific to alternating current [AC] conditions; in general the CAPACITANCE of a device changes from direct current (steady-state) to alternating current operations. Specifically, the RESISTANCE, inductance, reactance, and capacitance under alternating current become complex; FREQUENCY ($\nu = \omega / 2\pi$, where ω is the ANGULAR FREQUENCY) dependent; and parameters that have crossover properties, meaning the parameters are no longer linear and singular defined. Consider the current (i), a sinusoidal function with time (t), $i = I_{\max} \cos(\omega t)$, where $I_{\max}$ represents the maximum current (i.e., AMPLITUDE). For the charging process of a CAPACITOR this current now transforms into a function of the capacitance (C) and the applied voltage ($V_{\max}$), $i = \omega C V_{\max} \cos(\omega t)$, which translates to a current–voltage relationship defined by $V = (1/\omega C)I$, which yields a new parameter identified as the reactance, $X_c = 1/\omega C$, a derived capacitance. The frequency dependence will induce retardation in the current with respect to the driving voltage and can lag in PHASE. Indication of the amount of CHARGE (Q) that can be “steady-state” stored on a capacitor when a VOLTAGE (V) is applied, $C = Q/V$. The value of the capacitance is expressed in Farad [F], in actuality the value of capacitors in general use has a denomination of pF or μF . For a plate capacitor the capacitance is a function of the surface area (A), and the separation between the plates (d), $C = [\epsilon(N-1)A]/d$, where ϵ is the DIELECTRIC permeability and N the number of plates while $E = V/d = \sigma_{\text{elec}} / \epsilon = Q/A\epsilon$ indicates the electric field between the plates, with σ_{elec} the plate charge density. Because of the repulsive force between like charges, the charge distribution on a CONDUCTOR or semiconductor will be uniform, which does not hold true for an INSULATOR. Any object has a complex impedance, for instance the capacitance of a horse with respect to soil is approximately 150–200 pF, the hooves act as the insulation between “GROUND” or better, the dielectric separating the two sides of the capacitor. The storage of ELECTRIC CHARGE has many experimental observations culminating in the final description. Two

concurrent but separate events are notable in this historical development, around 1745 the world was pursuing the collection of what was thought to be “electric fluid,” now known as electric current. Both PIETER VAN MUSSCHENBROEK (1692–1761) and EWALD JURGENS VON KLEIST (1700–1748) performed experiments that illustrated the storage and respective discharge of charge in a container, mediated by the conductive interface of a wet hand holding the device, providing the means to discharge.

Capacitance, membrane

[biomedical, chemical, electronics] See MEMBRANE CAPACITANCE.

Capacitive reactance (X_c)

[biomedical, electronics, general] Because of time lag under alternating current charge distribution in an electronic circuit the capacitive charging requires introduction of a new complex parameter representing RESISTANCE. As described under CAPACITANCE (AC), $V = (1/\omega C)I$, which introduces the parameter defined as the capacitive reactance, $X_c = (1/\omega C)$.

Capacitive spectroscopy

[biomedical, electronics, imaging] PARTICLE counting under microfluidic conditions, specifically when the channel diameter is relatively large with respect to the particle diameter, put severe constraints on the equipment design. Polarizable micropillars can be used to provide a LIGAND-based capacitive system that specifically responds to certain molecular configurations. For instance, the use of polydimethylsiloxane can allow for such capacitive coupling counting system design. When an external ELECTRIC FIELD (E) is applied the capacitance (C) changes under the influence of the passage of the quantity of specific molecules. The current in the capacitive system will adhere to the EQUATION OF CONTINUITY, $\nabla \cdot J = 0$, where J is the current density, and OHM'S LAW (constitutive Ohm's law), $J = (\sigma + i\omega\epsilon_r\epsilon_0)E$, with ϵ_r the RELATIVE PERMITTIVITY and $\epsilon_0 = 8.854187817 \times 10^{-12}$ F/m the absolute permittivity of VACUUM, σ the conductivity per unit length of medium, and $\omega = 2\pi\nu$ the ANGULAR FREQUENCY of alternating applied voltage with frequency ν . The impedance (i.e., capacitance) can be calculated and plotted as a function of frequency in a BODE DIAGRAM (also referred to as a Bode plot) to derive the capacitive spectrum and hence the chemical composition of the FLUID passing through the “lab-on-a-chip.” This sensing technology is also referenced under IMPEDANCE SPECTROSCOPY.

Capacitor

[biomedical, electronics, general] Device capable of storing and releasing electrical charge, expressed in Farad (F). The capacitor design uses two conductors that are spaced apart by an insulating medium, such as GLASS, paper, polycarbonate, polyester (PET film), polystyrene, polypropylene, PTFE or teflon, silver mica, electrolytes, POLYMER, printed circuit board, and VACUUM. Next to conductors semiconductor materials are also used. A charge applied on a capacitor will be equal but opposite in value for the two respective plates. The capacitance (C) of the capacitor represents the ability to hold CHARGE (Q) and is defined by the electric field between the two charge layers or the electrical POTENTIAL (V) associated with this electric field, $C = Q/V$. Capacitors are made with various media, such as METAL plates separated by AIR (tuning capacitor, used in early RADIO design), ELECTROLYSIS (oxidized metal foil emerged in conducting gel), and ceramics. The ENERGY stored on a capacitor is the result of transferring a charge over an average potential $(1/2)V$, applying the capacitance yields $E = (1/2)CV^2$. Placing capacitors in parallel equate to increasing the surface area for the capacitive charge storage thus adding the individual capacities, whereas in series the total charge is equal for each capacitor and the combined capacitance equates: $C_{\text{equivalent}} = C_1C_2/(C_1 + C_2)$ or $(1/C_{\text{equivalent}}) = (1/C_1) + (1/C_2) + (1/C_i)$. A capacitor discharges its electrical charge while the voltage applied (V_{suppl}) over the external resistor (R) (i.e., impedance: X_{electric}) will drop accordingly, resulting in a time DECAY of the current (I) (i.e., charge released per unit time: t) expressed as $dQ/dt = I = C(dV/dt) = C(dIR/dt) = RC(dI/dt)$; solving for the charging phenomenon or respectively the

time release of charge yields $Q(t) = CV_{\text{suppl}}[1 - e^{-RC/t}]$; or discharge, $Q(t) = Q_0 e^{-RC/t}$, or for the charging current $I(t) = (V_{\text{suppl}}/R)e^{-RC/t}$. When the capacitor is charged and discharged resulting from an alternating current ($I_{\text{cap}}(t) = I_{\text{max}} \sin(\omega t)$), where ω is the ANGULAR FREQUENCY indicating the change in direction of the current through the capacitor (I_{cap}) per unit time; there will be a lag between the voltage and the current of precisely 90° or $\pi/2$ in PHASE, the current leading over the voltage with respect to time (see Figure C.11).

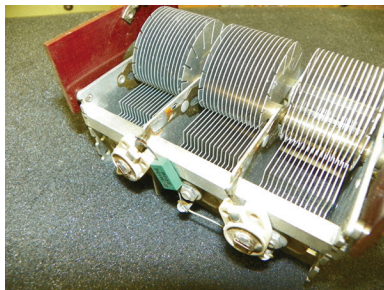


Figure C.11 Capacitor.

Capacitor, parallel plate

[electronics, general] See PARALLEL PLATE CAPACITOR.

Capacitor, radio

[general] Variable capacitance plate CAPACITOR used in early design FM and AM RADIO receiver and analog television receivers. The value of the capacitor determines the RESONANCE FREQUENCY of the receiving circuit, hence locking on to one specific radio transmitter SIGNAL only.

Capillarity

[fluid dynamics, thermodynamics] The surface interaction between a fine gauge hollow tube inserted into a LIQUID surface and the resulting surface shape and level height with respect to the surrounding free liquid inside a narrow column. The height of the liquid surface inside the tube with respect to the level liquid surface is a function of the DENSITY (ρ) of the liquid and the “adhesive forces.” For instance, the height (h) as a function of tube diameter (d) for the following liquids is as follows: mercury falls below the surface $h = -10/d$, water $h = 30/d$, or ALCOHOL $h = 11.6/d$. The surface curvature will make an ANGLE θ with the WALL of the tube that is directly dependent on the TENSION (F_T) between the liquid and the surface material of the tube (or the lining of the tube, e.g., OIL), $h = 4F_T \cos \theta / \rho g d$, where g is the GRAVITATIONAL ACCELERATION (see Figure C.12).

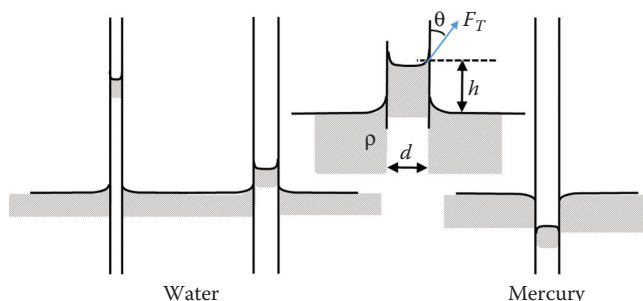


Figure C.12 Capillarity.

Capillary

[biomedical, biophysics, general] Small diameter tubing that results in hemodynamic conditions where residual forces become apparent in the FLOW mechanism of action as well as under steady-state conditions revealing the influence of forces between the WALL and the medium. One specifically notable situation is BLOOD flow in capillary systems of the circulatory vasculature under mechanical contraction of the HEART. The CAPILLARY FLOW is confined by the fact that the RED blood cells will flow through with minimal gradient force, which entails that the red blood cells line up as stacked parachutes, resulting in what is known as ROULEAUX FORMATION. In case the red blood cells are tilted there will be a gradient in force making the CELL straighten out with the edge of the circumference of the disk-shaped cell in cross-sectional contact with the wall of the tube, that is, capillary vessel. The full-circumference contact of the red blood cells results in a full mechanical contact with high FRICTION and frequently resulting in both vascular and red blood cell deformation, emphasizing the VISCOELASTIC properties of blood flow.

Capillary action

[fluid dynamics] (Greek: *capilla*: hair, i.e., hollow tube) Surface forces in the operational environment between a FLUID and a solid that are dominated by either cohesive or adhesive forces. The SURFACE TENSION for a certain LIQUID adheres to the WALL and wets the surface because of a polar attraction greater than the internal Van der Waals forces of the liquid. This phenomenon may cause the fluid to rise inside a narrow tube. The radius of curvature of the MENISCUS of the liquid in a tube with radius R is defined as $r = R / \cos \theta$, where θ is the ANGLE with the wall outside the liquid. The height (h) with which the liquid may rise depends on the density of the liquid ρ , expressed as the pressure of the column of liquid under gravitational attraction (g the GRAVITATIONAL ACCELERATION): $P = \rho g h$ compared to the force per unit area resulting from the surface tension over the curved surface, $2(\sigma_{\text{surface}}/r)$, yielding $h = 2\sigma_{\text{surface}} \cos \theta / \rho g R$.

Capillary flow

[fluid dynamics] FLOW is expressed as the integral of the velocity of medium over the cross-sectional area of a conduit with diameter $2R$. The velocity is the result of the pressure gradient ($P_1 - P_2$) over a length of a passage way (L), while the velocity can be a function of the radius (r) to the center of the conduit, $Q = (2\pi/4\eta)[(P_1 - P_2)/L]\int_0^R [R^2 - (r')^2] r dr'$, known as POISEUILLE'S LAW.

Capillary number (Ca)

[biomedical, fluid dynamics] Ratio of viscous force to elastic force, $Ca = \mu \dot{\gamma} a / b E$, when applied to vascular WALL where μ is the VISCOSITY, $\dot{\gamma}$ is the shear rate, a is the radius, b is the MEMBRANE thickness, and E is the membrane Young's modulus. For large diameter vessels the shear rate can still be large near the wall. The shear rate on the surface of the wall concomitantly leads to deformation of red BLOOD cells, and attributes to the formation of a flow-free layer at the vessel wall.

Capillary number ($Ca = \eta v / \gamma_s$)

[fluid dynamics] γ_s , SURFACE TENSION, η viscosity, v velocity. In the description of CAPILLARY FLOW, the capillary number ties together with the Bond number to describe conditions where the viscous stress between a BUBBLE and the WALL will be ruled by VISCOUS LUBRICATION. Under capillary flow transporting a bubble the FRICTION forces across the surface of the bubble can vary locally. Under certain conditions the bubble may be elongated and hence in close contact with the wall of the tube, which may be identified by a low, nonzero capillary number. Under these circumstances the surface of the bubble can be divided in regions that are subject to specific force

diagrams, respectively locally unique from tip to tail. The capillary number may additionally influence approximations and reductions in the NAVIER–STOKES EQUATION (see Figure C.13).

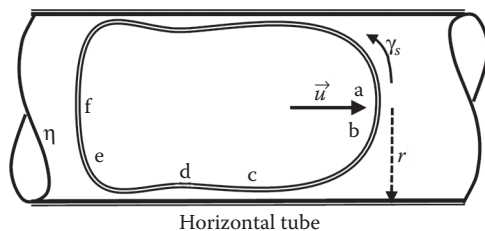


Figure C.13 The relation for the capillary number in bubble growth.

Capillary waves

[energy, fluid dynamics, mechanics] Ripples occurring at an interface between two liquids. One circumstance is the RIPLE wave resulting from wind on the surface of a LIQUID. Because of the size or MAGNITUDE, CAPILLARY wave grow and extinguish rapidly when the source (i.e., wind) engages or disengages. The WAVE process is confined primarily by the SURFACE TENSION (T_s). The breaking wave causes the FLUID pressure to become discontinuous at the surface in the crest. Assuming two curves are forming the crest, each with respective radius R , the discontinuity in the fluid surface PRESSURE (P) can be defined as $P - P' = T_s [(1/R_1) + (1/R_2)]$, where P and P' represent the pressure at the surface on either side of the crest. In the case of negligible influence of GRAVITY the VELOCITY POTENTIAL (ϕ) of the wave propagation in the x -direction with AMPLITUDE in the y -direction can be represented as $\phi = Ce^{ky} \cos(kx) \cos(\psi t + \varphi)$ and $\phi' = C'e^{-ky} \cos(kx) \cos(\psi t + \varphi)$, respectively, where C and C' are constants and $k = 2\pi/\lambda$ the wave number, ψ the imposed velocity, and φ a PHASE shift. This translates in a varying pressure under external force defined for one side respectively, $(P/\rho) = (\partial\phi/\partial t) = (\psi^2 a/k) e^{ky} \cos(kx) \sin(\psi t + \varphi)$, in case of a fluid density ρ . The surface deformation velocity is defined by $\psi = \sqrt{[T_s k^3 / (\rho + \rho')]}$, where ρ' the density on the “opposite side of the crest.” The wavelength is not a singular value, but rather forms a spectrum, ranging from low to high frequencies. The higher frequencies will be subject to DISPERSION and will cause the sharp crest to “break” eventually (on large scale this corresponds to braking wave at the beach in Hawaii, for instance). The driving force and the associated ENERGY of motion (KE) will determine the wavelength spectrum based on the velocity potential, $KE = (1/2)\rho \int_0^\lambda \phi (\partial\phi/\partial y)_{y=0} dx - (1/2)\rho' \int_0^\lambda \phi' (\partial\phi'/\partial y)_{y=0} dx$ for waves at the interface of two fluids. Under capillary wave MOTION the surface tension has an overpowering force influence on the wave description, acting as a restoring force. Generally, water waves with a wavelength less than 0.0173 m can be considered CAPILLARY WAVES. Both the PHASE VELOCITY and group velocity increase with decreasing wavelengths. The group velocity for capillary waves is greater than the phase velocity. At the crossover wavelength the phase velocity has a minimum value, approximately 0.231 m/s in a water–air fluid surface interface. Capillary waves can generally be recognized as small ripples, and result from a fresh wind blowing over smooth water. These waves have curved crowns and v-shaped troughs.

Capillary waves are extinguished by molecular “VISCOSITY.” For GRAVITATIONAL WAVES, in contrast, generally the crests are sharp and the troughs are rounded (see [Figure C.14](#)).



Figure C.14 Capillary wave.

Carathéodory, Constantin (1873–1950)

[computational, thermodynamics] Mathematician from Germany. The work of Dr. Carathéodory made significant changes in the computational approach to thermodynamic axioms. In axiomatic thermodynamics, the SOLUTION mechanism for the SECOND LAW OF THERMODYNAMICS relies on how to interpret the geometric configuration of a specific differential equation and the appropriate solutions, known as the PFAFFIAN. Carathéodory made significant strides in formulating thermodynamic laws in proper mathematical expressions. Carathéodory made statements with respect to the second law of thermodynamics concerning the mathematical definition of thermal concepts for a system (S_j), such as TEMPERATURE (T) and heat ($Q = \Delta U + W$, with the change of internal ENERGY U and the work W performed), described in mechanical terms of displacement (i.e., momentum: $p = mv$, with mass m and velocity v), volume (V), and PRESSURE (P). Each system will consist of different phases (e.g., LIQUID, solid), where the total energy of the system is the sum of the energy constituents of the various phases $\varepsilon = \sum \varepsilon_i (V_i, p_i, m_{ik})$, where k denotes the respective constituents, for the respective PHASE i . This has analogies with LORD KELVIN's (1824–1907) definition of temperature as the average kinetic energy (E) of a system, $E = (1/2)mv^2 = (3/2)k_b T$, where $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann constant.

Carbohydrate

[biomedical, chemical] Molecular structure principally consisting of carbon, hydrogen, and depending on the full macromolecular definition, including oxygen as an organic compound. Also referred to as saccharide. Examples of carbohydrates are sugars, wheat, and lactose. The carbohydrate designation is further subdivided in monosaccharides (e.g., GLUCOSE), polysaccharides (e.g., starch), disaccharides (e.g., lactose, sucrose), and oligosaccharides (e.g., inulin, also found specifically in AB BLOOD and on the MEMBRANE of cells where they form a marker in CELL to cell communications).

Carbon ($^{12}_6\text{C}$)

[atomic, biomedical, chemical, imaging] Organic ELEMENT. Part of molecular structures such as graphite and diamond as well as carbohydrates and organic fuels. Major atomic building block in organic structures, biological organism are composed of molecular chains containing carbon in a large percentage. This stable element has by definition the ATOMIC WEIGHT of 12.00000 atomic mass units (u). Stable carbon consists of 6 protons, 6 neutrons, and 6 electrons. Additionally, carbon isotopes are used in imaging applications since they will seamlessly integrate with the biological structure. Some of the available isotopes are ^{11}C and ^{14}C (see [Figure C.15](#)).

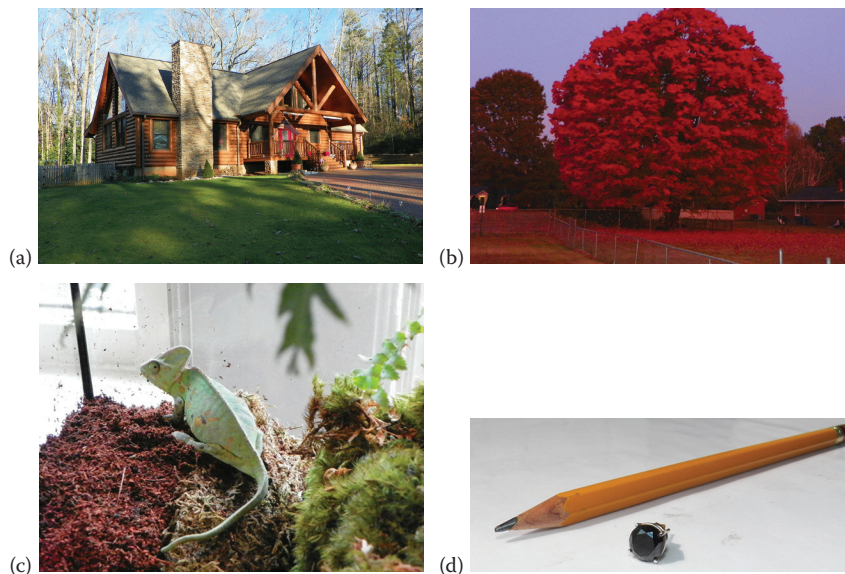


Figure C.15 Carbon is the building block of organic structures, as well as a fundamental ingredient for construction. (a) Log cabin made completely out of wood; (b) a tree; (c) a chameleon, biological life form; and (d) graphite tip of a pencil and a diamond earring.

Carbon radionuclide (^{11}C)

[biomedical, chemical, imaging] This unstable carbon ISOTOPE has a half-life of 20.4 min and is used in positron emission TOMOGRAPHY as a tracer in order to label physiological processes. The DECAY process of ^{11}C is by one positron.

Carbon radionuclide (^{14}C)

[biomedical, chemical] Major atomic building block in organic structures, biological organisms are composed of molecular chains containing carbon in a large percentage. The DECAY process of ^{14}C is by two electrons with a half-life of $\tau_{1/2} = 5,730$ years. The RADIOACTIVE ISOTOPE ^{14}C occurs in normal living carbon structures as a common “cousin” with a ratio of 1.3×10^{-12} to stable carbon-12 (same as the atmospheric ratio), and is used as a standard tool for radioactive dating of organic structures. During normal METABOLISM the standard ratio of ^{14}C to ^{12}C is maintained while after CELL death the ^{14}C will start to decay. Determining the remaining ratio provides the quantitative tools for radioactive dating.

Carbon-14 dating

[general, nuclear] Carbon ISOTOPE; ^{14}C is produced in the upper ATMOSPHERE as ^{14}N is bombarded by COSMIC RAYS. (Note: standard carbon has ATOM mass 12.) The ^{14}C drops to the EARTH where it is absorbed by plants and animals. The ^{14}C levels in an organism are constant throughout the organism's life (since it continuously adds and removes ^{14}C through nutrition and RESPIRATION). When an organism dies it can no longer replenish its ^{14}C levels and the ^{14}C begins to DECAY. Using the fact that the half-life for ^{14}C is 5730 years, RADIOACTIVITY levels of ^{14}C are measured and the level of decay from the original value is used to estimate the organism's AGE. This type of radioactive dating only applies to objects that have carbon as a base (primarily a metabolic base), not stones and such. There are however limitations to the accuracy and time range (see Figure C.16).



Figure C.16 Carbon dating of human skull.

Cardiac output

[biomedical, fluid dynamics] BLOOD flow principle recognized by ADOLF EUGEN FICK (1829–1901) as the total volume ejected by the contracting HEART per minute of time, expressed in liters per minute. The cardiac output (CO) is thus a function of both the volume of the ventricles and the heart rate (HR): heart rate multiplied by stroke volume (SV): $\text{CO} = \text{HR} \times \text{SV}$. The heart ejects a volume of blood based on the muscular function of the cardiac MUSCLE as well as the FLUID dynamic constraints resulting from the vascular RESISTANCE and COMPLIANCE in the whole body CIRCULATION. The circulation system comprises the AORTA on the left ventricular side and the pulmonary artery on the right ventricular side, branching out into a web of arteries, arterioles, and capillaries, flowing under a combination of venules and veins, leading back to the left and right atrium by means of the pulmonary veins from the lungs (carrying oxygen-rich blood) and the hollow VEIN (superior vena cava),

carrying oxygen-depleted blood, respectively. During exercise the cardiac output can increase by more than fivefold, depending on the training and general health of the individual.

Cardiac pacemakers

[biomedical] See PACEMAKER.

C

Carnot, Nicolas Léonard Sadi (1796–1832)

[computational, thermodynamics] French physicist who provided essential insight on the practical applications of the SECOND LAW OF THERMODYNAMICS in 1824 and may be credited as one of the cultivating founders of the essence of thermodynamics. Carnot's most remarkable asset is the theoretical description of a process that relies on the exchange of heat and the performance of work. The process has four (4) stages in an ideal mechanism; isothermal EXPANSION during delivery of heat (Q_H) at high temperature, followed by adiabatic expansion, with the third-stage isothermal compression, with heat exchange (i.e., loss) at low temperature heat (Q_L); and the fourth phase ADIABATIC COMPRESSION, ending up in the exact same energetic point in pressure and volume (PV plot) as where it left off. WORK (W) is performed during the isothermal expansion of stage 1 as well as the adiabatic expansion of stage 2. INERTIA or other stored ENERGY mechanism provides for the stroke in stage 3. Since the described Carnot process is ideal there is a reality associated with the efficiency of working devices and hence an associated efficiency: $e_c = \text{output of useful energy/delivered energy for the process} = W/Q = (Q_H - Q_L)/Q_H$. Examples of the efficiency of specific devices are as follows: electric MOTOR 50%–95%; GAS furnace for domestic heating 70%–85%; hydrogen–oxygen FUEL CELL 60%; nuclear power-plant 30%–35%; incandescent lamp 5% (see Figure C.17).



Figure C.17 Nicolas Léonard Sadi Carnot (1796–1832).

Carnot coefficient

[thermodynamics] Identification parameter for the distribution of the ENERGY “consumption” of a system, divided in two components: work performed on the external system and the disposal of the entropy received from both the external heat source and the entropy generated by the ENGINE. The CARNOT ENGINE primarily operates based on internal temperature (T_{in}) and the external temperature that drives the process (T_{out}), yielding the Carnot coefficient, $\eta_{Carnot} = (T_{out} - T_{in})/T_{out}$. This provides the ENTROPY (S) generated by an irreversible process as $S_{irr} = \eta_{Carnot} (Q_{out}/T_{in})$, where Q_{out} represents the energy transferred out of the system.

Carnot cycle

[energy, general, thermodynamics] (syn.: work) {use: cooling, heating, thermodynamics} A four-stage process where a GAS is expanded and contracted in two isothermal stages and two ISENTROPIC stages in interchangeable order. The Carnot cycle and CARNOT ENGINE principle were conceived by NICOLAS LÉONARD SADI CARNOT, a French scientist (1796–1832). The principles of the thermodynamics and the associated efficiency of ENERGY exchange processes and resulting work were first described in 1824 (see Figure C.18).

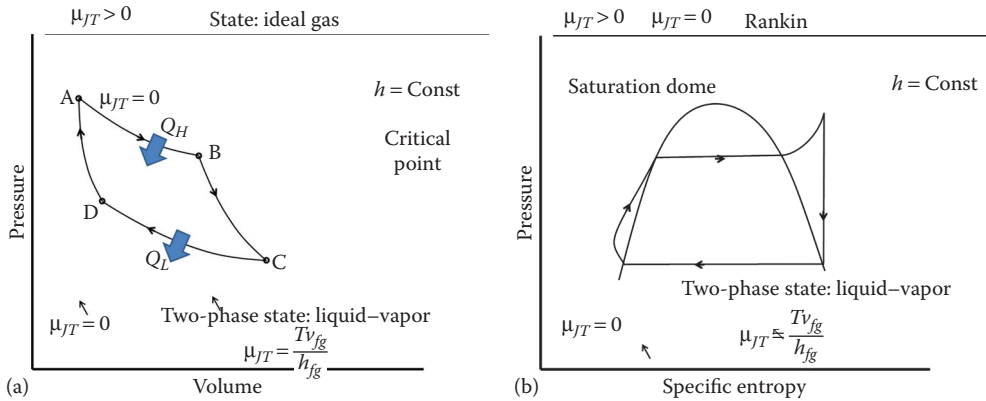


Figure C.18 (a,b) Pressure–volume diagram for a Carnot cycle at a specific temperature.

Carnot engine

[energy, thermodynamics] (syn.: work) {use: cooling, heating, thermodynamics} The Carnot engine consists of a cylinder and a piston, the compartment sealed off by the piston is filled with GAS and the reservoir is exposed to either low or high temperature resulting in a heat exchange process. Alternating the heat exchange (cooling/heating) results in the periodic EXPANSION and contraction of the sealed-off gas, moving the piston up and down.

Carrel, Alexis (1873–1944)

[biomedical] Vascular surgeon from France, who invented the mechanism of BLOOD oxygen exchange outside of the HUMAN BODY for which he received the Nobel Prize in PHYSIOLOGY and MEDICINE in 1912. This mechanism was adapted and incorporated in the first HEART–lung machine developed by Dr. JOHN HEYSHAM GIBBON (1903–1973). Together with CHARLES LINDBERGH (1902–1974) Carrel developed the first heart–lung machine in 1935.

Carrier

[biomedical] Protein chains that facilitate the transport of molecules through the biological CELL MEMBRANE at specific receptor sites. The respective individualized protein chains are highly specialized in the selection of molecules to transport. This transport system is classified as facilitated DIFFUSION, an active process.

Carrier wave

[general] Electromagnetic or acoustic WAVE in analog format that can be frequency or AMPLITUDE modulated to encrypt information for transmission to a remote receiver location. In digital format the mechanism of transfer is in bit rate, not in modulation. For television the transfer mechanism in the United States (in 2009) and in various other countries has changed from frequency modulation to digital encoding (using the same carrier wave for the respective channels/television stations). The carrier wave can be chosen to promote long DISTANCE propagation, whereas the modulation can be in the audible range or in a range that can be analyzed with some kind of spectral mechanism of action after the carrier wave has been removed by a demodulation scheme. In ELECTROMAGNETIC RADIATION amplitude modulation is

used in AM RADIO (150 kHz–26 MHz), whereas frequency modulation is used in FM radio (87.5 MHz–108 MHz). General FM radio is transmitted in stereo. RADIO stations perform the audio encoding for the transmission across the AIR ways to the audience. The STEREO modulation is obtained at two separate audio frequencies: v_{left} and v_{right} (i.e., multiplexing) with respect to the pilot tone (v_p), expressed as $\{0.9[(v_{\text{left}} + v_{\text{right}})/2] + [((v_{\text{left}} - v_{\text{right}})/2)\sin(4\pi v_p t)] + 0.1\sin(2\pi v_p t)\} \times 75 \text{ kHz}$. The audio SIGNAL in FM radio transmission is between 30 Hz and 15 kHz, defined as HiFi, or high-fidelity. The HiFi standard was introduced in 1966 to set the standards for accuracy in frequency transfer (reproduction of the input signal to the consumer) and low signal-to-noise ratio. The converted multiplexed signal is recombined in a decoder, which is part of the RADIO RECEIVER unit, and the output is transferred to an amplifier and relayed to speakers for the listening pleasure. Amplitude modulated radio waves generally have a short range, up to 200 km, whereas frequency modulated waves reaching into very short waves can travel extreme distances due to REFLECTION from the IONOSPHERE ranging from the opposite side of the world.

Cartesian coordinates

[general, mechanics] Coordinate system named after RENÉ DESCARTES (1596–1650), using two planes (two-dimensional) or three orthogonal planes (three-dimensional [coordinates: x,y,z]).

Cassini, Giovanni Domenico (1625–1712)

[astronomy, general, geophysics] Mathematician, astronomer, and engineer from Italy, and geophysicist. He completed the work of JEAN PICARD (1620–1682) on the longitude and LATITUDE angular division scale of the globe for cartography. In addition he discovered the split in Saturn's ring which was aptly named after him. He presented a thorough theoretical description of the precision of the axis of rotation of the MOON as well as the rotation period of several planets. Giovanni Cassini is known for his contributions on the description of our SOLAR SYSTEM, specifically the discovery of four satellites orbiting SATURN. Cassini also discovered the division of the rings of Saturn (not a continuous belt), which are named in his honor: Cassini Division. As an engineer Cassini worked on water management (FLOW control for rivers; specifically the river Po in Italy, known for its devastating flooding) as well as set out a topographical map of France in 1670, to be completed by his grandson, after the continuation by his son, in 1789. Cassini's name was also used for the (to date) 10 year mission to Saturn, as well as the in situ investigation by the National Aeronautics and Space Administration, powered by the Cassini spacecraft (see [Figure C.19](#)).



Figure C.19 Giovanni Domenico Cassini (1625–1712).

Cassini, Jacques (1677–1756)

[astronomy, general] French physicist, mathematician, and astronomer, son of GIOVANNI DOMENICO CASSINI (1625–1712). Cassini provided a detailed mathematical description of curvature of various closed loop shapes, primarily oval, and irregular shapes in the general outline of figure eight. These contracted oval shapes are sometimes referred to as cassinoids.

Cassini state

[astronomy, geophysics] A system is defined as residing in a Cassini state when it is in COMPLIANCE with the following three laws. The MOON revolves the EARTH in a 1:1 spin-orbit ratio, meaning that the same side of the Moon always faces the Earth. On second observation by GIOVANNI DOMENICO CASSINI (1625–1712) he found that the PRECESSION of the moon, describing a cone, is executed in a plane that intersects the elliptic orbit as a circle. The third conclusion from Cassini's observations was that the plane carved by the intersect from the normal to the rotational elliptic plane around the Earth with the plane described by the normal to the orbital plane around the SUN will contain the orientation of the rotational axis of the Moon as a function of location. These laws are known as the CASSINI'S LAWS. This applies in the scope of the processes to the mean orientation of a synchronously locked SATELLITE as well.

Cassini's laws

[astronomy, astrophysics, geophysics] Three sets of PLANETARY MOTION rules described by GIOVANNI DOMENICO CASSINI (1625–1712) in 1693, with mathematical geometric derivations of the position and orientation of the MOON with respect to EARTH. The same rules have been applied in setting the configuration of geostationary ORBITS for earth's satellites. With modifications these laws also appear to apply to the obliqueness of VENUS as well. The moon's axial rotation according to these laws is constrained as follows: (1) The Moon spins at a uniform rate that matches its mean orbital rotation rate; meaning the same side of the Moon always faces the Earth. (2) The normal to the moon's equatorial plane subtends a fixed ANGLE with the normal to the ecliptic plane as $\theta = 1.59^\circ$. (3) The normal to the moon's equatorial orbital plane, the normal to general orbital plane of the Moon, and in addition to the normal to the ecliptic lunar plane form three coplanar vectors that are orientated in such a manner that the vector describing the ecliptic lunar plane is confined by the other two planes.

Cassiopeia

[astronomy, astrophysics, general] The location of the Cassiopeia constellation is found in reference to the NORTH STAR (POLARIS) (Polaris is fixed in our view of the northern sky), which is part of the URSA MINOR (LITTLE DIPPER), with URSA MAJOR (BIG DIPPER) to one side and Cassiopeia of the lower other side (the relative position will change with the seasons as the rotational axis of the earth pivots [PRECESSION]); to the right in SUMMER and to the left of Polaris in WINTER. The shape of Cassiopeia is more or less a flattened "W" (see Figure C.20).



Figure C.20 Outline of the constellation Cassiopeia.

Casson, N. (twentieth century)

[fluid dynamics] Relatively unknown fluidic behavior engineer who published his model of viscous behavior in 1959, known as the CASSON MODEL, or the fluids as Casson fluids.

Casson model

[biomedical, fluid dynamics, general] Non-Newtonian FLOW model of colloid suspensions such as BLOOD, dough, and chocolate under low shear rate. The VISCOSITY is defined as $\eta_{\text{visc}} = (\sigma_{s,0}/\dot{\gamma}) + \sqrt{(k_C \sigma_{s,0}/\dot{\gamma}) + k_C}$, where $\sigma_{s,0}$ is the material yield stress, $\dot{\gamma}$ the shear rate, and k_C the Casson constant or Casson rheological constant. Note that based on the FÄHRAEUS–LINDQVIST EFFECT the determination of the apparent viscosity is a function of the device and methods used to derive the viscosity. Specifically there are four primary device mechanisms in use to determine the viscosity: two concentric rotating cylinders; rotating disk with respect to stationary plane separated by a LIQUID thickness; rotating cone with respect to stationary plate; and measure of flow rate through a CAPILLARY tube (*also see* VISCOSITY MODEL). It is also known as Casson equation.

CAT scan

[general] Computerized axial TOMOGRAPHY, also known as CT scan or X-RAY tomography. X-ray IMAGE reconstruction resulting from multiple sequential or parallel transmission measurements at incremental ANGLES completing a 360° circumferential scan. The computational component is in the calculation of the intersects of lines from various (multiple and incongruent) angles for identification of points in the two-dimensional dissection plane that have equal attenuation, providing the triangulation for the location of the anatomical features for the image reconstruction. The axial component is added by moving the scanning array in the axial direction by discrete stages, or through the use of multiple X-ray sources and detector arrays that are stacked in a scanning belt. Once all the measurements have been acquired from 360° circumferential scans as well as axial increments, a three-dimensional reconstruction is performed by means of a computer program that renders a visualization. The visualization can be selected by choosing slices at azimuthal and ZENITH angular orientations in order to identify regions with X-ray density that is different from the NORMAL DISTRIBUTION peak or that are sharply distinguished from the neighboring volumes (see [Figure C.21](#)).



Figure C.21 CT scanner X-ray machine.

Cathode

[biomedical, chemical, electronics, general] Negatively charged ELECTRODE, usually accompanied by the positively charged ANODE, as introduced by MICHAEL FARADAY (1791–1867). The word “cathode” comes from the Greek word for “the direction in which the SUN sets.” Both the cathode and anode submerged in a SOLUTION of ACID, SALT, or base will divide the constituents of the respective electrolyte(s) based on the sign of the charge. The positive (CATION) and negative (ANION) charged ions will diffuse respectively to the cathode and anode under the influence of the applied electric field resulting from an external electrical potential source (e.g., BATTERY, chemical reaction), which is required to be stationary in order to induce the ionic migration.

When direct current (consisting of electrons) between the electrodes is applied to pure water the **ELECTRIC CHARGE** gradient between the cathode and the anode will result in **IONIZATION** of the water ($4\text{H}_2\text{O} \rightleftharpoons 2\text{HO}^- + 2\text{H}^+ + 2\text{H}_2\text{O} \rightleftharpoons 2(\text{H}_3\text{O})^+ + 2\text{HO}^- \rightleftharpoons 4\text{O}^{2-} + 8\text{H}^+ \leftrightarrow 4\text{O}_2 + 8\text{H}_2$), which is a poor **CONDUCTOR**. The formation of the $(\text{H}_3\text{O})^+$ **ION** is temporary, and is due to the inherent attraction between the polarized water molecule and the hydrogen ion with **POSITIVE CHARGE** (cation). Upon reaching the respective anode and cathode, the respective cation and anion will lose their charge in exchange with the electrodes and form oxygen (O_2) and hydrogen molecules (H_2). The **ELECTROLYSIS** of water can be enhanced by the addition of an **ACID**, such as carbonic acid, sulfuric acid, nitric acid, or perchloric acid. The speed of the electrolysis will greatly depend on the strength of the acid (acidity) expressed in **pH**. Electrode will be at negative electrical potential, with respect to the anode which is at a positive electrical potential. A heated cathode will emit electrons, forming **CATHODE RAYS**. The electron emission will provide a free space current, with current density J , which can be calculated with the use of Richardson's law, $J = (1 - \tilde{r})(4\pi em_e k_b^2 / b^3) T^2 e^{-(\phi_{\text{elec}}/kT)}$, also referred to as **DRIFT** current density or displacement current density; defined as a function of temperature T , using Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$; electron charge equivalence, $e = 1.60217657 \times 10^{-19} \text{ C}$; ϕ_{elec} the work function; electron mass, $m_e = 9.10939 \times 10^{-31} \text{ kg}$; $b = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, and $\tilde{r}$ the mean **REFLECTION** coefficient for the material surface ($\tilde{r} \cong 0.5$ for tungsten). The concept of displacement current also applies to the time-dependent **MAXWELL EQUATIONS** (see **Figure C.22**).



Figure C.22 Cathode ray vacuum tube.

Cathode glow

[atomic, nuclear] Low-pressure **GLOW DISCHARGE** first described in 1675 by the French astronomer **JEAN PICARD** (1620–1682). It wasn't until 1870 that **SIR WILLIAM CROOKES** (1832–1919) provided a formal description of the cathode glow, and introduced the investigational **ELECTRODE** tube, the **CROOKES TUBE**. The Crookes tube was the predecessor to the modern neon light signs.

Cathode ray tube (CRT)

[biomedical] **VACUUM** tube with a **CATHODE** that emits electrons and a hollow **ANODE** to provide a **PROJECTILE** electron (electron gun) that can be deflected by electrodes before it impacts a fluorescent screen. CRT was the elementary component in old-fashioned televisions and **OSCILLOSCOPE** screens. The monitors predating the flat-panel display, **PLASMA** screen, and **LED** screen are referred to as CRT screens. CRT screens are bulky and heavy due to the large amount of **GLASS** and **ELECTRONICS** involved. Additionally due to the

construction of the CRT mechanism of action these devices are consuming a significant amount of electrical ENERGY, with inherent generation of heat (see [Figure C.23](#)).

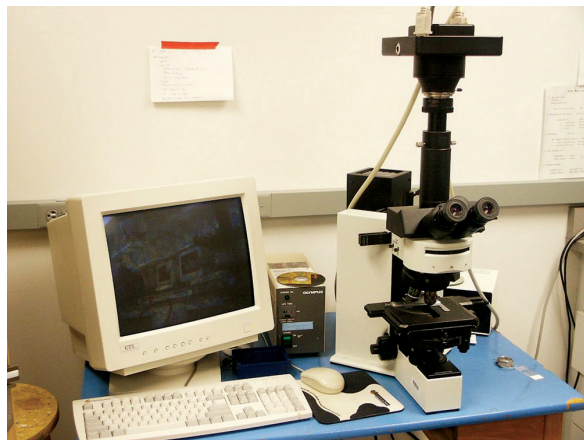


Figure C.23 CRT computer monitor attached to a camera mounted on an optical microscope.

Cathode rays

[atomic, nuclear] Electron beam, emitted from the CATHODE in a VACUUM TUBE or CROOKES TUBE (after SIR WILLIAM CROOKES [1832–1919]).

Cation

[chemical, electronics] ION that is attracted to the CATHODE, hence carrying a net POSITIVE CHARGE. The process of ion DIFFUSION applies in particular to ELECTROLYSIS and atmospheric AIR IONIZATION coronas.

Cauchy, Augustin-Louis (1789–1857)

[general] Mathematician, physicist, and engineer from France. Cauchy provided significant details on the description of stress and strain on MICROSCOPIC scale based on the initial MACROSCOPIC definitions by ROBERT HOOKE (1635–1703) more than a century prior in 1676. Another mathematical contribution by Cauchy is the SOLUTION method based on the residues of the developed series with respect to a function (see [Figure C.24](#)).



Figure C.24 Drawing of Augustin-Louis Cauchy (1789–1857).

Cauchy method of residues

[computational, fluid dynamics, general] Mechanism of complex function analysis named after AUGUSTIN-LOUIS CAUCHY (1789–1857). The “residue” theorem applies to solving integrals over closed curves in the complex domain. Consider a function (f) that is analytic and holomorphic inside the curve of the domain carved out by the integral loop as well as on the points of the curve of the closed integral path, but is not analytic in the points inside the curve within the complex domain $z_j = x_j + iy_j$: excluded points $z_1, z_2, \dots, z_n$ (i.e., singular points). The function can be developed in a Laurent series as: $f(z) = \sum_{n=-\infty}^{\infty} a_n (z - z_j)^n$, where the coefficient of a_{-1} with respect to $1/(z - z_0)$ is the *residual* of the function $f(z)$ in z_0 ; $\text{Res}[f, z_0] = a_{-1}$. For instance the Laurent function for $f(z) = e^{i/z}$ around the point z_0 can be written as $f(z) = 1 + (2^1/1!)(1/z) + 2^2(1/2!z^2) + 2^3(1/3!z^3) + \dots$ with $\text{Res}[f, z_0] = a_{-1} = 2$. The Cauchy method of residues is described by the algorithm: $\int_C f(z) dz = 2\pi i \sum_{k=1}^n \text{Res}[f, z_k]$, where the residue of the function f at any point z_j is $\text{Res}[f, z_j]$. This is also tied to the Cauchy integral $f(a) = 1/2\pi i \oint f(z)/(z - a) dz$ (see Figure C.25).

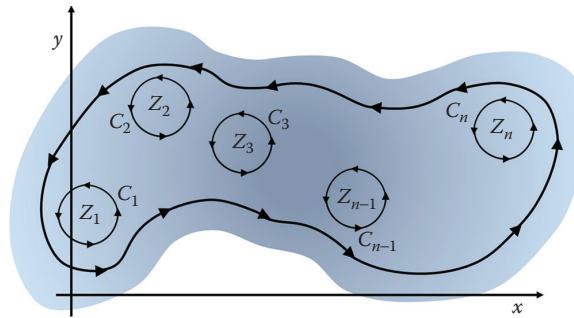


Figure C.25 The Cauchy residue method.

Cauchy number ($C = \rho v^2/E$)

[engineering, fluid dynamics] This number identifies regimes in FLUID FLOW WHERE compressibility is a factor of influence, named after a contributor in the field AUGUSTIN-LOUIS CAUCHY (1789–1857). This number describes the relative importance of inertial and elastic forces under compressible flow conditions; in fact the ratio of the inertial forces to the compressible forces. The Cauchy number is a function of the fluid DENSITY (ρ), as well as the flow VELOCITY (v) and the elastic modulus of the fluid medium (E). The Cauchy number is closely related to the MACH NUMBER and is often expressed as the Mach number to the second power.

Cauchy strain tensor

[fluid-dynamics, mechanics] $\varepsilon = \nabla \vec{v} + (\nabla \vec{v})^T \sim E$, where E is the LAGRANGIAN FINITE STRAIN TENSOR and $\vec{v}$ the deformation or FLOW velocity (solid respectively FLUID).

Cauchy–Poisson wave problem

[computational, fluid dynamics] Mathematical problem introduced in 1815 by AUGUSTIN-LOUIS CAUCHY (1789–1857) and SIMÉON DENIS POISSON (1781–1840) regarding the WAVE propagation on a (slightly compressible) LIQUID at the surface, with finite depth (h). The displacement follows from the local PRESSURE (P) and DENSITY (ρ) as $P/\rho = (\partial\phi/\partial t) - g\zeta + F(t)$, under the condition that the Laplace derivative of the VELOCITY POTENTIAL (ϕ) equals zero $\nabla^2\phi = 0$, ζ the vertical displacement, x and y the propagation directions, g the GRAVITATIONAL ACCELERATION, and $F(t)$ the time-perturbed influence function (e.g., storm). As boundary conditions the displacement pressure will satisfy $\xi = 1/g[\partial\phi/\partial t]_{\zeta=0}$, as well as $\partial\xi/\partial t = -[\partial\phi/\partial t]_{\zeta=0}$. The SOLUTION can be written with the use of a Bessel function of zeroth order ($J_0(k\varpi)$, $\varpi = r \sin \theta$; the surface rotational displacement, wave with curve of radius r , respectively $\zeta = -r \cos \theta$), using the wave number $k = 2\pi/\lambda$,

where λ represents the wavelength, provided $\phi = gt/2\pi \int_{-\infty}^{\infty} \{k - (gt^2/3!)k^2 + [(gt^2)^2/5!]k^3 - \dots\} e^{kz} J_0(k\varpi) dk \approx (gt/2\pi) \{ [P_1(\cos\theta)/r^2] - (gt^2/3!) [2!P_2(\cos\theta)/r^3] + [(gt^2)^2/5!] [3!P_3(\cos\theta)/r^4] \}$, after developing the pressure in a series, while the displacement satisfies $\xi = t/2\pi\rho\varpi^3 \{1 - [(1)^2(3)^2/5!] [(gt^2)2/\varpi] + (1^23^25^2/9!) [(gt^2)^4/\varpi] - \dots\}$, which for $(gt^2/2\varpi) \gg 1$ yields: $\xi = (gt^3/2^{7/2}\pi\rho\varpi^4) \sin(gt^2/4\varpi)$. Note that the WAVEFRONT can be described by $r = t\sqrt{(gb)}$.

C Cauchy–Riemann equations

[computational, fluid dynamics] Based on the Cauchy integral $f(a) = (1/2\pi i) \oint f(z)/(z-a) dz$, and the fact that holomorphic functions are analytic it follows $f^n(a) = n!/2\pi i \oint f(z)/(z-a)^{n+1} dz$. For an arbitrary disk ($\mathbb{D}$) within the closure ($\mathbb{C}$) of the integrand it can be shown for $\chi \in \mathbb{D} \subset \mathbb{C}$, for which $f(\chi) = 1/2\pi i \int_{\mathbb{D}} [f(z)/(z-\chi)] dz + 1/2\pi i \int_{\mathbb{D}} (\partial f(z)/\partial \bar{z}') [d\bar{z}' \wedge dz'/(z-\chi)]$, where $\wedge$ is the “logical” “and” for the integration constraints to the complex function. The latter integral provides the tools to solve the Cauchy–Riemann equations with respect to two variables, $u(x, y)$ and $v(x, y)$, as expressed in the thesis by the German mathematician Georg Friedrich Bernhard Riemann (1826–1866) in 1851, based on the work by JEAN LE ROND D’ALEMBERT (1717–1783) published in 1752, LEONARD EULER (1707–1783) published in 1779, and with finishing touches by AUGUSTIN-LOUIS CAUCHY (1789–1857) in 1814. The Cauchy–Riemann equations are expressed as $\partial v(x, y)/\partial y = \partial u(x, y)/\partial x$ and $\partial u(x, y)/\partial y = -\partial v(x, y)/\partial x$, with respect to the complex number $z = x + iy$ as $f(x + iy) = u(x, y) + iv(x, y)$, a holomorphic function.

Cavendish, Henry, Lord (1731–1810)

[general] Scientist, chemist, physicist, and British nobleman of French origin, one of the wealthiest men of his days. Cavendish derived the universal gravitational constant in 1728 as $6.75 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$, compared to current day accepted standard, $6.67259 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$ (see [Figure C.26](#)).



Figure C.26 Lord Henry Cavendish (1731–1810). (Courtesy of George Wilson.)

Caveolae

[biomedical] Location of actively formed invagination in the CELL MEMBRANE to support the ENDOCYTOSIS processes. The process results in the formation of vacuole or vesicles used to transport solid or LIQUID material intended for consumption or processing.

Cavitation

[biomedical, fluid dynamics, general] Sudden decrease in volume (collapse) of EXPANSION (e.g., mechanical deformation or vapor BUBBLE; NUCLEATION) that exerts forces on the surrounding media and materials. Generally the formation of bubble progresses at a slower rate than the collapse, providing a unique mechanism

of mechanical interaction. Cavitation may result from interaction of ULTRASOUND pressure wave with soft materials (i.e., initiated by mechanical forces), specifically biological media. Additional occurrences of cavitation can be described resulting from thermal ablation processes, specifically short duration events, such as pulsed laser ablation (i.e., initiated by THERMAL EXPANSION). The cavitation process is accompanied by shear waves that will obey the WAVE EQUATION with associated propagation of effects. Depending on the material properties the wave can be critically damped ranging to undamped. Cavitation can provide mechanical effect as well as chemical changes. The collapse of a spherical bubble can be associated with a KINETIC ENERGY (KE) that is a function of the rate of change over TIME (t) of the bubble radius ($r = r(t)$) expressed as $\dot{r} = dr(t)/dt$, with respect to the initial radius R_0 with associated internal pressure P_1 , defined using the density $\rho = \rho(t)$ as $KE = 2\pi\rho r^3 \dot{r}^2 = (4/3)\pi P_1 (R_0^3 - r^3)$. The true nature of the bubble collapse is more intricate, specifically when involving ionized PLASMA created during an ablation process (e.g., laser vaporization) or when condensation occurs during the size reduction of the bubble. During condensation the density of the VAPOR bubble changes and hence other CONSERVATION LAWS need to be included in the theoretical evaluation process. The rate of change in bubble diameter can be described as a wave phenomenon. Assuming the special case of adiabatic expansion/collapse the rate of change is captured by a surface velocity equivalent (i.e., $v_s' = \sqrt{(P_1/\rho)}$; “constant” parameter with the dimensions of velocity) in second-order derivative ($\ddot{r} = d^2r/dt^2$): $\ddot{r} + (3/2)\dot{r}^2 = v_s'^2 (R_0/r)^{3\gamma_a}$, where γ_a represents the adiabatic factor (defined as the ratio of the SPECIFIC HEAT [$c_{sp} = Q/m\Delta T$, describing the HEAT (Q) required to change the TEMPERATURE (T) of a MASS (M) by 1 K] of the GAS in two phases of the RAREFACTION vs. expansion processes), which ties pressure and density together as $P/P_0 = (\rho/\rho_0)^{\gamma_a}$. The rate of heat exchange of the bubble to the surrounding LIQUID medium is primarily subject to the NUSSELT NUMBER (Nu) of the system. The FORCE (F) exerted by the cavitation process at any specific point in the collapse is directly proportional to the momentary change in kinetic energy ($W = \Delta KE$, i.e., the work) over the DISTANCE traveled by the surface of the bubble captured by incremental delta in radius (Δr), $W = F\Delta r$ (see Figure C.27).

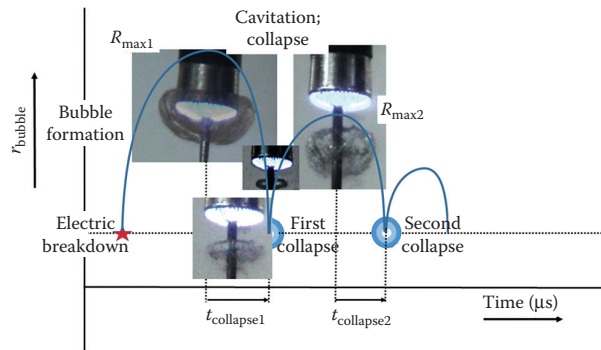


Figure C.27 Cavitation process for bubble generated by laser heating resulting from nanosecond laser pulse.

Cavitation number ($\sigma_c = 2(P - P_v)/\rho v_{\text{flow}}^2$)

[energy, fluid dynamics] Ratio of “static pressure” gradient in relation to KE density, where P is the local pressure, P_v the fluid VAPOR PRESSURE, v_{flow} the FLOW velocity (average), ρ the fluid density. In addition to PIPE flow, especially in a curved vessel, this will also be very useful in determining the impact of shape and angular velocity in PROPELLER action. Even though this may resemble the Euler number the functionality is entirely different.

CCD

[computational, electronics, quantum, solid-state] See CHARGE-COUPLED DEVICE.

CCD camera

[electronics, fluid dynamics, optics, quantum, solid-state] Charge-coupled device semiconductor structure from which the top layer has been removed which makes the charge layer light sensitive and can be used in

array form to capture images that are limited in RESOLUTION by the number of CCD unites in the array or matrix format (see [Figure C.28](#)).

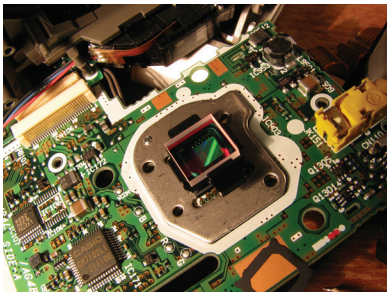


Figure C.28 Picture of digital camera using CCD element for registration of light spectrum and radiance.

CCT

[general, optics] Correlated COLOR temperature. The COLOR appearance of LIGHT emitted by a source, primarily a lamp. The color of source light is related to the EMISSION from a reference source heated to a particular TEMPERATURE, measured in KELVIN (K). The correlated color temperature classification for a LIGHT SOURCE, however, does not give information on its specific SPECTRAL DISTRIBUTION, more so on the appearance of the color of objects illuminated by the source. Two lamps may visually appear to be the same color, while the respective visual experience of object colors can be significantly different (*also see* VISION) (*see* [Figure C.29](#)).

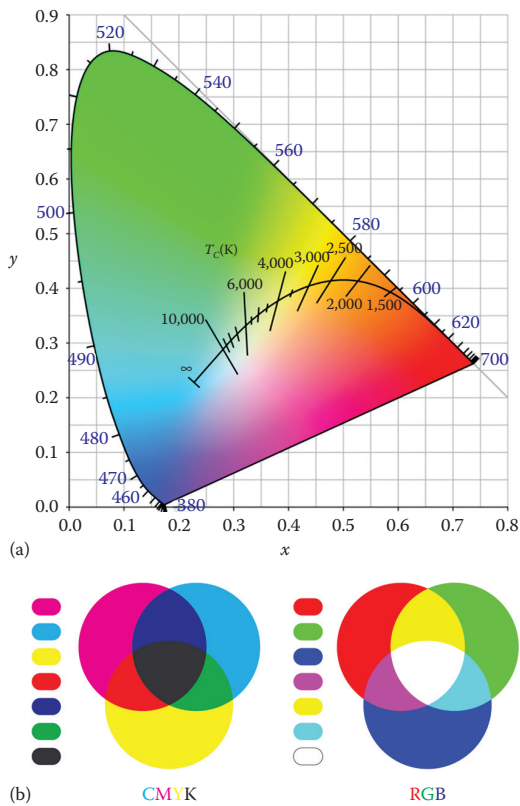


Figure C.29 Correlated color temperature map: (a) CIE 1931 x, y chromaticity space. (b) Color chart outlining the difference between the CMYK standard (cyan–magenta–yellow–black), for instance, used in dyes with a subtractive character, and the RGB (red–green–blue) standard.

Celestial bodies

[astronomy/astrophysics, general, mechanics] Any object in galactic space, ranging from planets (e.g., EARTH) to galactic dust and stars. The escape velocity for an object from any celestial body with mass M is the minimum speed (v_e), in perpendicular direction, required to overcome the gravitational attraction of the body with radius R and gravitational constant G and can be defined as $v_e = \sqrt{(2GM/R)}$. Note that the release from higher altitude (e.g., from a plane at cruising altitude) changes the radius (r) factor to the location specifics, which becomes $\sqrt{2}$ times the orbital equilibrium VELOCITY (v_{tan}): $v_{\text{tan}} = \sqrt{(GM/r)}$ for stationary orbit, where centripetal (tangential) force balances the gravitationally confined orbital force (see Figure C.30).



Figure C.30 A full moon (celestial body) in the eastern sky.

Cell

[biomedical, chemical, energy, solid-state] There are several types of cells to be defined: primarily we are familiar with the biological composition of single- and multicell organisms and secondarily the charge pump cell in a BATTERY needs to be considered. The biological cell has a lipid–protein dynamic bilayer forming the CELL MEMBRANE that encloses the intercellular FLUID, which may contain the NUCLEUS with genetic information and physically adjusts to external SHEAR FORCE and strain, reinforcing weak spots as well as providing a mechanism to actively move the cell by means of changing the configuration of the enclosure. Cells can grow and form semipermanent adhesions to other structures and other cells. The ameba is an example of a single-cell organism, whereas the species *Homo sapiens* has a multitude of specialized cells that form organs, supporting structures, muscles as well as a highly configurable communications network. For a battery the electrical potential that can be achieved is a function of the materials used, the HALF-CELL potential. In biology the half-cell potential is derived from the NERNST POTENTIAL equation for the specific ions in place at either side of the cell membrane: $\epsilon_{\text{ion}} = (RT/FZ_{\text{ion}}) \ln([{\text{Ion}}]_{\text{out}}/[{\text{Ion}}]_{\text{in}})$, where $R = 8.3144621 \text{ J/Kmol}$ is the GAS constant, $F = 9.64853399 \times 10^4 \text{ C/mol}$ is the FARADAY CONSTANT, Z_{ion} the ionic charge, $[{\text{Ion}}]$ represent the concentration of a specific ION, respectively, on the outside or inside of the cell membrane and T the ABSOLUTE TEMPERATURE. At the body temperature of 37°C , the equation yields $\epsilon_{\text{ion}} = 61.5 \times \ln([{\text{Ion}}]_{\text{out}}/[{\text{Ion}}]_{\text{in}})$, which provides for chlorine with respective intracellular concentration $[{\text{Cl}}^-]_{\text{in}} = 9.0 \text{ mM}$, and extracellular concentration $[{\text{Cl}}^-]_{\text{out}} = 125.0 \text{ mM}$; $\epsilon_{\text{Cl}^-} = -70 \text{ mV}$, which can be experimentally verified. The galvanic half-cell potential is $\epsilon_{\text{ion}} = RT/F \ln(a_{\text{ion}}/\sqrt{(P_{\text{ion}}/P^0)})$, where $a_{\text{ion}} = \exp[(\mu_i - \mu_i^\ominus)/RT]$ is the “ACTIVITY” of the ion SOLUTION with the chemical potential $\mu_i = (\partial G/\partial N_i)_{T,P,N_{j \neq i}}$ (also known as the partial molar ENERGY) where G represents the Gibbs free energy and N_i the particulates for the respective constituents under the operational conditions (concentration $[{\text{ion}}]$, pressure $[P]$, and temperature $[T]$) and with

respect to a chosen standard state $\mu_i^\ominus$, representing the partial solution as if it responds as an ideal chemical solution, P_{ion} is the partial pressure of the ionic solution respectively gas, expressed in Pascal, and P^0 is the standard pressure 10^5 Pa. The half-cell potential can also be defined in terms of acidity (pH) of the solution as $\varepsilon_{\text{ion}} = -(\Delta G^\ominus/nF) - (0.05916/n)\log(\{a_A\}^a\{a_B\}^b/\{a_C\}^c\{a_D\}^d) - (0.05916b/n)\text{pH}$, where the number of released electrons is described by n as in the chemical process: $aA + bB + n[e^-] + b[H^+] \rightleftharpoons cC + dD$, describing the range of chemical constituents and their respective quantities in the reaction (see Figure C.31).

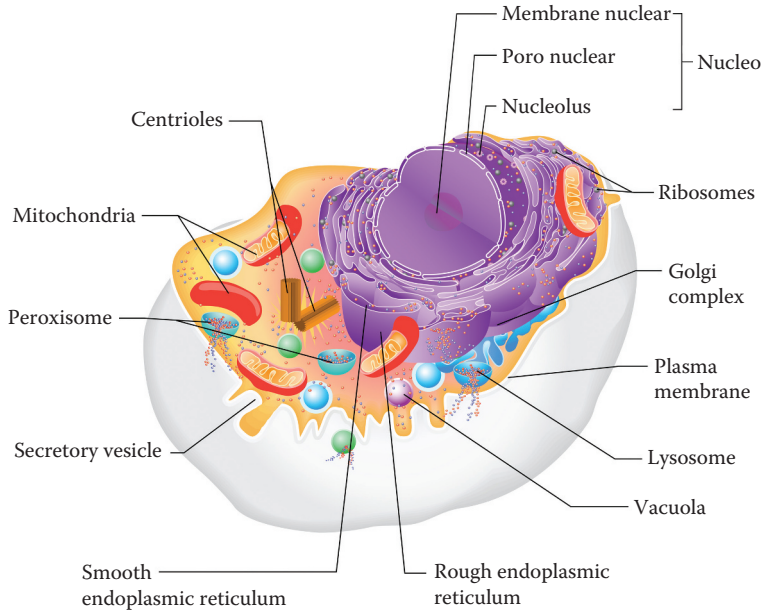


Figure C.31 Biological cell.

Cell, electrically responsive

[biomedical, electronics] In biological media there are certain cellular configurations that allow the individual cells to respond to electrical influences that are extremely small in MAGNITUDE. One specific example is the sensory organ in the head of certain sharks that can detect electric field strengths as small as 10^{-6} N/C . In comparison the background RADIATION in outer space is $\sim 3 \times 10^{-6} \text{ N/C}$, the electric wiring in the average household produces field strengths in the order of 10^{-2} N/C , and LIGHTNING produces approximately 10^4 N/C . The sensory PERCEPTION of the SHARK provides capabilities to detect MUSCLE contractions from several kilometers DISTANCE.

Cell composition and response to radiation

[biomedical, nuclear] Cells respond to RADIATION depending on the type of radiation (α [Helium ion]; β [electron]; γ [EM radiation]; etc.) and dose. Additionally, radiation exposure is cumulative, leading to a slow build-up before catastrophic response is achieved. Damage can be affected on the CELL MEMBRANE and on the DNA, as well as total cell death. Damage may be reversible or irreversible. Although the initial deposition of the ENERGY may be very short (order of 10^{-17} s), the large-scale implications are directly proportional to the ENERGY of the applied radiation and the mechanism of action: PARTICLE or ELECTRO-MAGNETIC radiation. The biological change in specific cells as a result of radiation may occur after a latent period. The duration of the delay in time depends on initial and cumulative dose and may vary, depending on the type (i.e., energy) of the radiation ranging from minutes to years. One specific radiation response may be an altered communication behavior, changes in the chemical responses.

Cell junction

[biomedical, chemical, fluid dynamics, mechanics] CELL to cell interaction (e.g., communication) is mediated by cell junctions that provide a mechanism for protein binding (e.g., ligands) and define the response to deformation. Cell junctions are regions in the CELL MEMBRANE of a biological medium that are enriched with specific proteins that provide a means of interaction (signal exchange, electrical or chemical, and potentially optical) between two adjacent cells. They also provide a mechanism to sustain SHEAR STRESS (σ_s), which is of particular importance in the GASTROINTESTINAL TRACT (GI tract) and BLOOD vessels. The shear stress is a function of the VISCOSITY (η) of the FLUID IN MOTION, the FLOW (Q), and the radius (r), $\sigma_s = 4\eta Q / \pi r^3$. The RESISTANCE to shear stress characterizes the specific cell junctions, in particular for the lumen in question. Three types of cell junctions can be identified: (1) desmosomes, (2) tight junctions, and (3) gap junctions. Desmosomes (zonulae adherens) are located in tissues that are under the influence of shear stress, for instance the SKIN and GI tract. The desmosomes are proteins that form a strong intercellular bond as well as a strong bond to the basal LAMINA (extracellular matrix [ECM] layer that is formed by secretion from the epithelial cells). Desmosomes provide a regenerative/reconstructive mechanism to the cell membrane under deformation, in particular with respect to the organization of the cytoskeleton. Tight junctions on the other hand are found in tissue providing a specific exchange function, such as the KIDNEY (nephron cells), the endothelial cells in the blood vessels (nutrients, oxygen, waste exchange) as well as the nutrient resorption by the enterocytes in the GI tract (intestines). Tight junctions have specific functions to prevent the movement of proteins in the cellular membrane, in particular those that serve an apical function (chemical sorting function, for instance found in the Golgi complex [also known as Golgi apparatus]; named after the Italian scientist and physician Camillo Golgi [1843–1926]). Gap junctions are found for instance in the ORGAN OF CORTI in the cochlea of the EAR, supporting the SIGNAL transduction in response to deformation by movement of the hair cell. Gap junctions are composed of six connexin proteins (Cx) that form hemichannels, also known as connexons. The connexons will align for proper sharing of cytoplasm between neighboring cells. The sharing mechanism is based on small molecules (<1000 Da) and ions providing both electrical and chemical signal transduction through “messengers.” Generally, the GAP JUNCTION transfer of molecules and ions does not require ENERGY; however, the HEARING effort is certainly facilitated by the ATPase activity and recycling of K^+ ions. The gap junction provides a selection mechanism for which ions may pass by means of POLARIZATION of the connexions and the molecular orientation. In addition to the interaction with adjacent cells by means of the cell junction, the cell junctions also support communication with ECM. ECM is one of the key components for multicellular organisms and is composed of a collection of extracellular molecules that is purposely secreted by cells and provides both biochemical and structural support. ECM is composed on any or multiple of the following constituents: collagens, fibronectin, LAMININ, as well as vimentin and vitronectin. Cells are attached to the ECM by means of INTEGRINS (transmembrane receptor molecule acting as a bridge between cells and between cells and the ECM). The integrins provide a chemical response to shear stress (deformation), which is specific for the transmembrane receptor kind. Finally, the cell junction provides interaction with the cellular scaffolding, also known as cytoskeleton, which is an integral part of the cellular structure and support the intracellular transport as well as support cell division. The cellular scaffolding comprise three kinds of filaments: microfilaments, intermediate filaments (IF), and microtubules. The microfilaments form a support mechanism by integrating with the double-helix ACTIN chains in the vicinity of the cellular membrane. The microtubules provide the transportation support. All components of the cellular scaffolding support the shape and in particular the resistance to deformation and tension. The MEMBRANE resilience to deformation can be defined by the membrane stiffness (Ei) and the deformation length L as $F = 3Ei/L^2$. The function of the cytoskeleton in this regard is the restructuring of the cell membrane to compensate for tension by means of actin (F-actin, a component of the cytoskeleton), IFs, and microtubule filaments. Specifically, the IFs provide a membrane “motor function,” providing molecular realignment and thickening of the cell membrane in compensation for the applied deformation. The adjustments are made in steps in the order of 8 nm with local force applied by the cytoskeleton in response to the cell junction efforts in the order of 6 pN.

Cell membrane

[biomedical] Lipid–protein bilayer that encloses the cellular PLASMA and in most cases a NUCLEUS containing the biological DNA. The MEMBRANE is a living structure that can adjust to chemical challenges as well as mechanical influences resulting from both internal and external forces. The CELL MEMBRANE accommodates chemical and particulate transport through ENDOCYTOSIS next to facilitated gated transport through pores. Mechanically, the cell can modify its cell membrane to become resilient to local stress and strain resulting from external influences on both MICROSCOPIC and MACROSCOPIC scale. The macromolecular structure provides an elastic configuration that supports an active lifestyle. External forces can be found resulting from high-frequency vibrations, as well as pressure gradients resulting from local osmotic pressures as well as gravitational influences. Additional external forces may result from FLUID FLOW resulting in shear stress. Internal forces include the chemical configuration making up ACTIN and MYOSIN to form cytoskeletal cables that orchestrate cellular movements as well as morphological changes. Other external influences include hydrostatic pressure and ADHESION from neighboring cell, next to growth. A free (nonenclosed) body of LIQUID is subject to LAPLACE LAW, whereas the cell membrane forms an equilibrium by means of both stretch and modification. The TENSILE FORCE (F_t) on the membrane for this situation is expressed as $F_t = K_a (\Delta A / A_0)$, where ΔA is the increase in surface area for the bilayer with respect to the original area A_0 and K_a is the area EXPANSION constant (range: 10^{-1} – 10^1 N/m), where the tension 3×10^{-3} N/m $< F_t < 3 \times 10^{-2}$ N/m. With surface area expansion the membrane thickness (d) will change proportionally, $\Delta A / A_0 = \Delta d / d_0$, where the response to shear stress of the membrane describes it as an elastic solid (see Figure C.32).

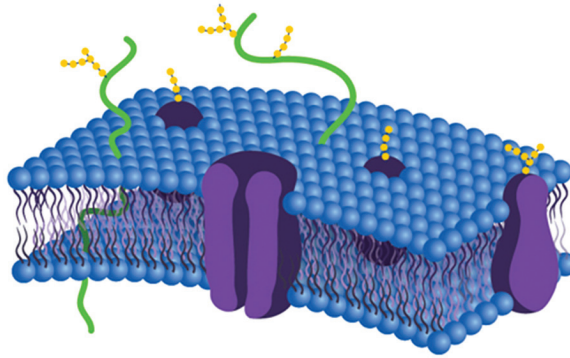


Figure C.32 Artist impression of the design of a biological cell membrane.

Cellophane

[biomedical] Regenerated CELLULOSE ACETATE, used as a filtration mechanism in the early days of dialysis MACHINES (~1930s), following the recurring infection rate when using peritoneal membranes (obtained from the abdominal lining).

Cellular automata

[computational] System definitions with an abstract foundation that are used in discrete mathematics problem solving. These concepts are equivalent to the field concept in field equations in general PHYSICS. Another analogy may be drawn with respect to the wavelet concept in SIGNAL processing, which is both place and time confined. Under this computational approach, the space is divided into a uniform matrix format that contains array parameters which are called the “cells.” Each CELL is associated with a state variable defined in digital format. For each cell, time progresses in incremental steps, not continuous,

and frequently relies on a “look-up” table as the provider for the definition of the state. The fact that the system can be solved for a finite number of steps in time with respect to a finite segment of the system lends this mechanism ideal for parallel computing, and for that MATTER for cluster computing, since all system segments are defined to be noninteractive, each with the same local and uniform sets of rules.

Cellular signaling

[biophysics, chemical, energy] Biological cells communicate with neighboring cells as well as with the autonomic and PARASYMPATHETIC NERVE SYSTEM to regulate their own metabolic and reproductive ACTIVITY as well as balance with the organ or tissue they are an integral part of. In addition, the cells regulate their natural chemical and energetic balance by secretion of chemical signals as well as electronic charges which interact with its cellular MEMBRANE and the extracellular conditions. The extracellular conditions can involve the secretion of hormones or the opening or closing of ports on the cell's own or neighboring cell's membranes (PHAGOCYTOSIS, PINOCYTOSIS, active processes as well as the ACTION POTENTIAL specifically). Some of the signaling processes involve soluble factors, primarily proteins, other are ionic in nature. Some of the signaling processes are identified by their specific mechanism as follows: AUTOCRINE, HORMONAL, PARACRINE, and SYNAPTIC SIGNALING.

Cellulose

[biomedical, chemical] Artificially constructed as well as naturally occurring polymer. POLYMER materials that are degradable and biocompatible, made from β -D-glucose (6-carbon sugar) monomers, that is, polysaccharides, are called cellulose. The long molecular configuration provides cellulose with its inherent strength. Cellulose is the main component forming the cellular matrix of plants CELL walls. Cotton is a more specific example of naturally occurring material composed of cellulose. This material was used in artificial lung devices developed in the 1950s and 1960s to generate a SEMIPERMEABLE MEMBRANE from the transport of oxygen to BLOOD in an extracorporeal system. Additional applications are found in drug delivery, sutures, tissue ENGINEERING, and bandages and wound dressings. Cellulose can be reconstituted with chemical treatment to break lignin bonds and reformed with the aid of alkali media or bisulfites, followed by cross-linking the cellulose fibers to form paper (see [Figure C.33](#)).



Figure C.33 Raw cotton with greater than 90% cellulose content.

Cellulose acetate

[biomedical, chemical] Acetate ester formed from CELLULOSE, which can be reconstituted to form CELLOPHANE. Cellulose acetate was first produced in 1865. Cellulose was made to react with acetic anhydride to form cellulose acetate (one of the foundation materials used in the production of photographic emulsions). Several applications are available under commercial names. Other examples of applications of cellulose acetate are in textiles (often in blends with other materials, such as cotton and NYLON), cigarette filters, and frames for EYE glasses. Cellulose acetate can be spun into strands for weaving, for instance, acetate rayon.

Cellulose nitrate

[biomedical, chemical] Chemical result of the treatment of CELLULOSE with sulfuric ACID and nitric acid. Chemical component used in the construction of extremely thin microporous membranes, for instance used to encapsulate artificial biologically active components such as sensing chemical ELEMENT transducer lining with the chemical ligands separated from the TRANSDUCER. Other applications are in paint (lacquer) and explosives. Cellulose nitrate can be used to produce TRANSPARENT film sheets and light-sensitive “transparent” sheets and roles used in cameras. With AGE, chemicals degrade, culminating in the release of acidic by-products such as nitric oxide, makes the cellulose nitrate unstable and highly flammable, it will even burn under water. It is also known as NITROCELLULOSE, guncotton, flash cotton, or flash paper.

Celsius, Anders (1701–1744)

[general, thermodynamics] Astronomer from Sweden, generally known for his introduction of the CELSIUS SCALE used in temperature MEASUREMENT. Anders Celsius followed the inspiration of CARLOS RENALDINI [RINALDINI] (1615–1698) who performed his temperature measurements at least 50 years prior. Another contemporary metrologist was DANIEL GABRIEL FAHRENHEIT (1686–1736), competing in the English culture with the Fahrenheit scale (see Figure C.34).



Figure C.34 Painting of Anders Celsius (1701–1744).

Celsius scale

[general, thermodynamics] Generally accepted measure for temperature (T) in household use, established by ANDERS CELSIUS (1701–1744) as the total range of observable expressions of average molecular KE defined as temperature ($T = (2/3k_B)\bar{E}$, where $k_B = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the Boltzmann constant) in relative format as introduced in 1741. Sometimes one may still find Celsius defined as CENTIGRADE. The principle of measuring temperature by means of liquid EXPANSION can be attributed to the Italian scientist Ferdinand II de' Medici, the grand duke of Tuscany (1610–1670), dating back to approximately 1654.

The temperature scale generally uses three points as reference to define the temperature. The Celsius scale uses the boiling point of water at 1 atmosphere pressure ($T_{\text{boil}} \equiv 100^\circ\text{C}$); the PHASE TRANSITION point from solid to LIQUID for H_2O recognized as the MELTING POINT, also referenced as the FREEZING point ($T_{\text{melt}} \equiv 0^\circ\text{C}$); and additionally the triplet point for water is expressed with respect to the Kelvin temperature scale as $T_{\text{Triplet}} \equiv 273.16\text{ K}$. The Celsius scale is the range of temperatures from melting point to boiling point subdivided in 100 incremental steps. Other temperature scales are the Fahrenheit scale introduced by GABRIEL DANIEL FAHRENHEIT (1686–1736) in 1717 (still used in the United States) as well as the absolute Kelvin scale, next to scales from past exercises; Réaumur (defined by the French scientist RENÉ-ANTOINE FERCHAULT DE RÉAUMUR [1683–1757]) and RANKINE (defined by the Scottish scientist WILLIAM JOHN MACQUORN RANKINE [1820–1872]). The THERMOMETER used to express the Celsius scale uses either ALCOHOL or mercury in a closed tube, relying on linear THERMAL EXPANSION ($\Delta\ell = \alpha(T_2 - T_1)$, where α is the linear expansion coefficient and ℓ the length of the medium) of the medium to indicate a MAGNITUDE when lining up with a calibrated scale according to the Celsius definitions. The first thermometer invented is attributed to GALILEO GALILEI (1564–1642) dated circa 1595, using GAS expansion to raise or lower the hydrostatic pressure in a tube; hence raising or lowering the liquid level of the open container medium connected to the gas-filled tube. Other thermometer mechanisms from early stages of thermodynamics work are based on gas or liquid expansion principles. Later mechanisms of action used for the determination of temperature use PLANCK'S LAW and rely on the black-body RADIATION captured by optical spectroscopic techniques. ABSOLUTE TEMPERATURE SCALES are expressed in Kelvin or Rankin, both referencing the point of lowest temperature with no MOLECULAR MOTION as the zero point. A useful conversion between degree Fahrenheit (T_F) and degree Celsius (T_C) is $T_C = (5/9)(T_F - 32)$.

Celsius (second century AD)

[biomedical] Egyptian scientist and medic. Author of an encyclopedia of MEDICINE called the “DE MEDICINA.”

Center of gravity

[biomedical, mechanics] The virtual point in the volume of a body where for convenience the forces are apparently acting upon. A body in equilibrium requires that the sum of the forces through the center of gravity align with the normal force. In case the normal force and sum of acting forces do not line up, the system forms a torque that will result in rotation. The center of gravity may be defined for a specific subsection of a total system, for instance the foot of a human, in reference to the entire HUMAN BODY.

Center of mass (r_{CM})

[general, mechanics, nuclear] The point inside the outline of a body of a system where all mass can be considered to be concentrated. For instance, for an air-filled rubber ball all the mass is in the rubber shell whereas the center of mass is in the center of the ball. The location of the perceived single mass in a reference frame of choice as summarized over all the masses ($\sum_i m_i = M$) (each respective mass [m_i] constituent identified by i) as a function of each respective location (r_i) contributed from a system of particles (regardless of size and structure; including atoms and molecules) or concurrently the location of the combined effect of all the masses of the constituents of a device with various components and materials. The definition of the center of mass is formulated as $r_{\text{CM}} = \sum_i r_i m_i / \sum_i m_i$. The center-of-mass will directly influence the determination of the moment of INERTIA for an object. The center of mass will also be the point where all forces (F_i) are considered to be acting on the object providing the acceleration to the center of mass ($\overline{a_{\text{cm}}}$) in NEWTON'S SECOND LAW, $\sum \vec{F} = m \overline{a_{\text{cm}}}$. The location of the center of mass and dimensions of a body directly determine the moment of inertia for that body, specifically if the body is nonuniform and has various geometric extensions of certain composition and materials that hold mass. The location (R) of the center of mass in a coordinate system is defined by the components of an object, each with respective mass (m_i) and respective DISTANCE to an origin (r_i) in a coordinate system, defined by the total mass ($M = \sum m_i$) as $R = \sum_i m_i r_i / M$. The relative position (r^*) of each of the components (i) can now be defined for a specific subsection (k) as

$r_k^* = r_k - R$; similarly the velocity is defined by $v_k^* = v_k - V$, where V is the velocity vector for the system. Under relativistic conditions (approaching the speed of light $[c]$, which applies to nuclear conditions), the velocity needs to be corrected by means of the LORENTZ TRANSFORMATION, which translates in the momentum ($p = mv$) formulation as follows: $\vec{p}_k^* = \vec{p}_k - [(\gamma_{cm} e_k / c) - \gamma_{cm}^2 / (\gamma_{cm} + 1)(\vec{\beta} \cdot \vec{p}_k)] \vec{\beta}$, where the quantum ENERGY is $e_k = m_k c^2 / \sqrt{(1 - \{v_k / c\}^2)}$ and “inertial energy” $\vec{\beta} = \sum_i \vec{p}_i c / e_i$ and $\gamma_{cm} = \sum_i e_i / E^*$. In this the QUANTUM energy is defined as $E^* = \sqrt{[(\sum_i e_i)^2 - (\sum_i \vec{p}_i)^2 c^2]}$. In the Lorentz transformation the momentum components that are orthogonal to the parameter $\vec{\beta}$ are conserved, while the parallel components are modified. This last description can be applied under various conditions, including COMPTON SCATTERING (see Figure C.35).



Figure C.35 A high jumper is manipulating her center of mass to enhance the high jump level when performing a pole vault jump during the different vaulting phases.

Centered difference

[computational, fluid dynamics] Computational technique used to isolate extremes by using the half-intervals $(\Delta b/2)$ in the first derivatives of a function $f(f'(x_i) = [f(x_i + (\Delta b/2)) - f(x_i - (\Delta b/2))]/\Delta b) + O(\Delta b)$ when derived over incremental step size Δb , the error is expressed by $O(\{\Delta b\}^2)$. The slope connecting these two points and respective accuracy can be expressed in (and is directly dependent on) the increment step size. Increasing this into a Taylor series the derivative has a second component: $f'(x_i) = -f(x_i + (2\Delta b/2)) + 8f(x_i + (\Delta b/2)) - 8f(x_i - (\Delta b/2)) + f(x_i - (2\Delta b/2))/12(\Delta b/2) + O(\{\Delta b\}^2)$ the second-order difference now becomes $f''(x_i) = [f(x_i + (\Delta b/2)) + f(x_i) - f(x_i - (\Delta b/2))]/\{\Delta b/2\}^2 + O(\Delta b)$ and $f''(x_i) = [-f(x_i + (2\Delta b/2)) + 16f(x_i + (\Delta b/2)) - 30f(x_i) - 16f(x_i - (\Delta b/2)) + f(x_i - (2\Delta b/2))]/12(\Delta b/2) + O(\{\Delta b\}^2)$, which uses the centered differences around x_i . This SOLUTION method is frequently used in computational FLUID DYNAMICS, primarily since the NUMERICAL solution needs to be solved in a finite ELEMENT configuration due to the complexity of the local boundary conditions.

Center-seeking forces

[general, mechanics] Any object with mass (m) moving in a curved trajectory (e.g., circular, elliptic motion) with certain tangential VELOCITY (v) will be forced to follow the curved path with radius of curvature (r) under the influence of a CENTRIPETAL FORCE. The centripetal force (F_c) is directed toward the center of the

curvature with MAGNITUDE $F_c = ma_c = mv^2/r$; this force may result from FRICTION (tires on the pavement), normal force (barrel racing), or TENSION (e.g., rope) (see [Figure C.36](#)).



Figure C.36 Merry-go-round with center-seeking force.

Centigrade

[thermodynamics] See CELSIUS.

Centimeter

[general] Metric system. Fractional unit of DISTANCE/length, 1/100 of the SI unit meter.

Centripetal force

[general, mechanics] Circular MOTION obtained by balancing forces, determining the MAGNITUDE of the CENTRIPETAL FORCE maintaining the object in revolution, $F_c = mv^2/R$, where m is the mass of the PROJECTILE, v the velocity of motion, and R designates the radius of curvature of the circular motion. Force is required to keep a moving mass travel in a circular path and should be directed toward the axis of the circular path.

Cepheid variables

[astrophysics, energy, mechanics] Named after the prototype Delta Cepheid. Indication of the mechanical properties of stars, specifically the oscillatory behavior.

CERN synchrotron

[atomic, mechanics, nuclear, quantum] High-energy PARTICLE ACCELERATOR located in Switzerland, at the French border, near the city of Geneva. The particle accelerator is formed in a large circular loop with radius R . An applied voltage alternates with a single period determined by the condition $T = 2\pi m/qB$. The particle accelerator uses a MAGNETIC FIELD (B) to generate a force ($F = qvB = m(v^2/R)$) on a charged particle

with charge q and mass m to induce acceleration resulting in a maximum velocity $v_{\max} = qBR/m$, with KE upon exit from the CYCLOTRON $(1/2)mv^2 = q^2B^2R^2/2m$ (see Figure C.37).

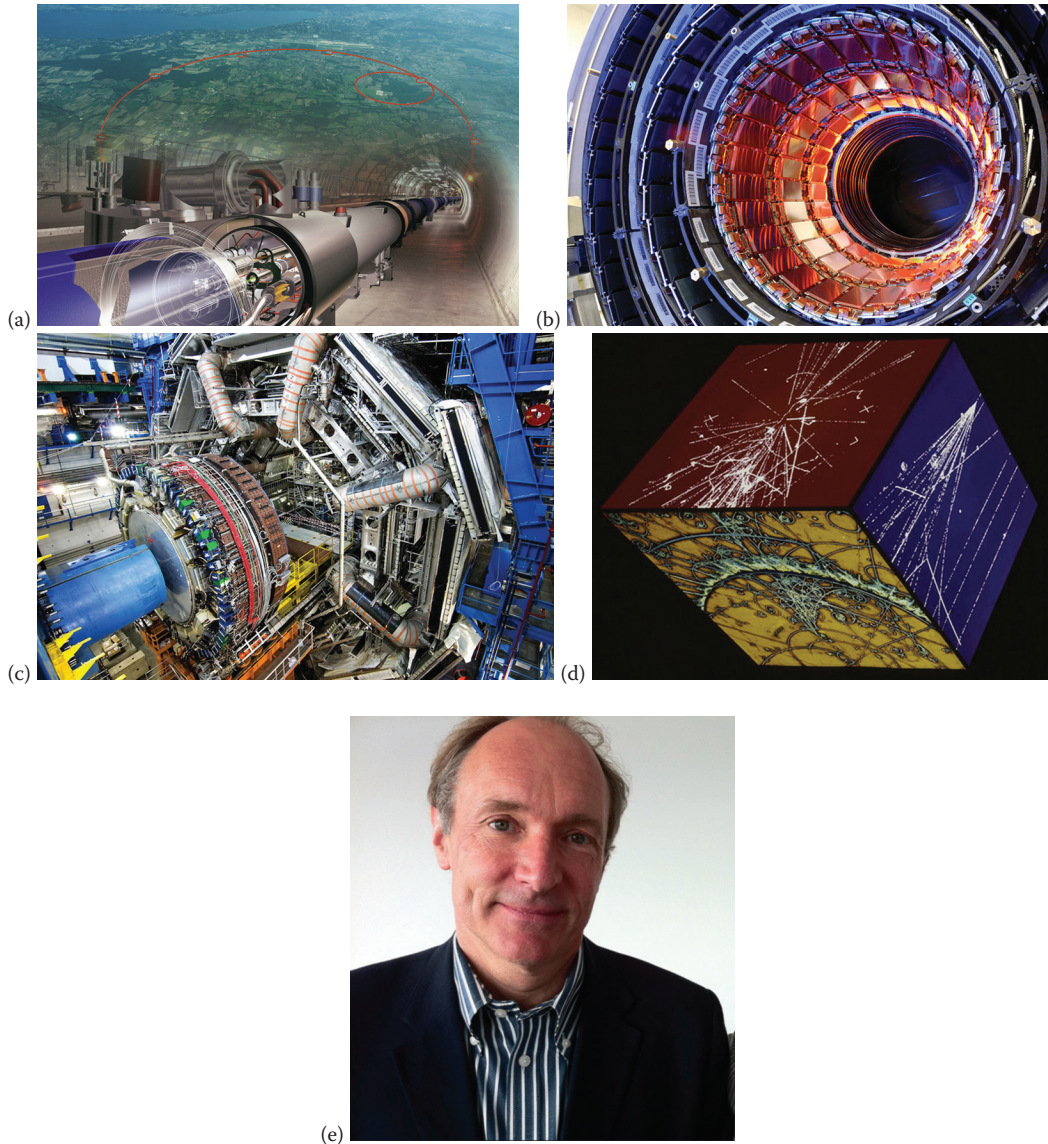


Figure C.37 CERN (“Conseil Européen pour la Recherche Nucléaire,” or European Council for Nuclear Research) facilities and operations in Meyrin, Switzerland: (a) outline of the 27 km diameter facilities of the European Organization for Nuclear Studies with beam guide (Large Hadron Collider: LHC) as insert. (Courtesy of CERN, Geneva, Switzerland.) (b) Compact Muon Solenoid (CMS) inner tracker barrel consisting of three layers of silicon modules placed at the center of the CMS (LHC) experiment, guiding 14 TeV proton–proton collisions, the silicon that is used will be able to withstand the powerful magnetic field and high doses of radiation without damage. (Courtesy of Maximilien Brice, CERN, Geneva, Switzerland.) (c) Calorimeter used to measure the energy of particles that are produced during collision of protons, close to the axis of the beam, chilled inside a cryostat to provide optimal operational conditions for the detector. This is part of the LHC used to verify the Higgs boson and provide an insight into the origin of dark matter. (Courtesy of Claudia Marcelloni, CERN, Geneva, Switzerland.) (d) Simulation of particle trajectories. (Courtesy of CERN, Geneva, Switzerland.) (e) The World Wide Web was conceived at CERN by the scientist Sir Timothy John “Tim” Berners-Lee (1955–) from Great Britain in 1989, the use of the Internet made the transport of large amounts of data easy and convenient. (Courtesy of Rory Cellan-Jones, BBC, London, UK.)

Chadwick, James (1891–1974)

[atomic, general, nuclear] Physicist from Great Britain. In 1914 Chadwick described the release of electrons with different energies, introducing the concept of RECOIL ENERGY to the atomic and nuclear interaction from PROJECTILE PARTICLE interaction. Chadwick worked with Rutherford on the definition of the nuclear composition and in 1932 described the release of the neutron (n) resulting from the bombardment of beryllium (Be) with ALPHA PARTICLES (α), ${}^4_2\alpha + {}^9_4\text{Be} \rightarrow {}^{12}_6\text{C} + {}^1_0n$, also producing CARBON (see [Figure C.38](#)).



Figure C.38 James Chadwick (1891–1974).

Chain reaction

[chemical, general] Any chemical or nuclear process in which some of the products of the process are instrumental in the continuation or magnification of the process.

Chandrasekhar, Subrahmanyan (1910–1995)

[astronomy/astrophysics, biomedical, energy, general, optics] Indian mathematician who theoretically described the RADIATIVE TRANSFER of ENERGY within stellar ATMOSPHERES. The radiative transfer theory was

toward the end of the twentieth century successfully adapted for biomedical purposes in light tissue interaction—EQUATION OF RADIATIVE TRANSFER (see [Figure C.39](#)).



Figure C.39 Subrahmanyan Chandrasekhar (1910–1995).

Chandrasekhar mass

[astronomy/astrophysics, energy, quantum] The gravitational mass of a STAR where GRAVITY will overcome the Fermi ENERGY and collapses, $M \sim 1.44 M_{\odot}$, where $M_{\odot}$ represents the solar mass. Stellar mass less than the Chandrasekhar mass will not possess enough energy to produce neutrons, thus preventing the formation of a NEUTRON STAR by means of the constraints to the electron DEGENERACY. At a mass less than the Chandrasekhar mass the star will only be able to produce a WHITE DWARF. This also defines the theoretical upper limit for the mass of a stable white dwarf. The electron density (N_e) for the star defines the Fermi energy of that star, $E_F = (5/3)(1/N_e)C(N_e^{5/3}/R)$, where R defines the equilibrium radius for the star and C is a constant for the star (based on its history and size).

Characteristic X-ray

[atomic, nuclear] See X-RAY, CHARACTERISTICS.

Charge (q)

[electronics, general] Excess or shortage of electrons in an atomic or molecular system that produces either negative or POSITIVE CHARGE. On a nuclear level the excess protons can provide a positive charge. The concept of two different charges was officially introduced by BENJAMIN FRANKLIN (1706/1705?–1790) in 1747; however, the concept of charge was known and has been described as far back as ancient Greek philosophers and old Chinese documentation dating back well before Christ on the Christian/western calendar. It is also referred to as ELECTRIC CHARGE.

Charge conjugation

[computational, relativistic, thermodynamics] Under a LORENTZ TRANSFORMATION all particles are transformed into their respective antiparticles. The operator is discontinuous and applies only to RELATIVISTIC–QUANTUM–MECHANICAL situations. The charge conjugation follows the pattern outlined for space INVERSION and time reversal.

Charge density wave

[atomic, solid-state, thermodynamics] Periodic charge density fluctuations in a low-dimensional METAL LATTICE structure. Because of an interaction between electron density in free FLOW and phonon propagation an electron density WAVE pattern is generated with a periodic charge density modulation that has a rhythmic intermittent lattice distortion superimposed, causing a charge density wave pattern. Each perturbation is associated with the Fermi wave vector. The phonon spectral pattern that results is referred to as the KOHN ANOMALY. The periodic PHASE transitions induced by the electron charge density fluctuations generate a wave pattern with a wavelength $\lambda_{\text{charge}} = \pi/k_F$, where k_F is the FERMI WAVE VECTOR. The wavelength may be commensurate with the LATTICE CONSTANT, however not so when the lattice has only partially filled electron bands. When the lattice density perturbations are disorganized, the PARTICLE gap occurring at the FERMI LEVEL will create an INSULATOR.

Charge per unit area (σ_e)

[general] Total charge that is distributed evenly on a “two-dimensional” object per unit area.

Charge per unit length (λ_e)

[general] Total charge that is distributed evenly on a “one-dimensional” object per unit length.

Charge-coupled device (CCD)

[computational, electronics, quantum, solid-state] Capacitive semiconductor material structure that can be used to temporarily store ELECTRIC CHARGE. The storage time can be controlled by external circuitry and can be used to form a delay line (time delay) and concurrently acts as a “bucket memory,” temporarily storing the electronic information and transferring it over to the next CCD in the circuit. The stored information is primarily binary, but there are also analog applications.

Charles, Jacques Alexandre César (1746–1823)

[general] Scientist and physicist from France. Charles' work was in the behavior of ideal gasses with pre-IDEAL GAS LAW definitions. Cotemporary of JOSEPH LOUIS GAY-LUSSAC (1778–1850) (see [Figure C.40](#)).



Figure C.40 Jacques Alexandre César Charles (1746–1823). (Courtesy of the United States Library of Congress, Washington, DC.)

Charles's law

[atomic, nuclear] GAS LAW introduced by JACQUES ALEXANDRE CÉSAR CHARLES (1746–1823) with respect to the VOLUME (V) and temperature (T) of an IDEAL GAS expressed as $V/T = \text{constant}$ for constant pressure and number of moles. It is also known as the GAY-LUSSAC LAW.

Charm

[general] Classification of ELEMENTARY PARTICLES, specifically quarks. In reference, an electron can be identified by spin-up or spin-down. In the construction of rudimentary particles, mesons consist of a QUARK and an antiquark, whereas a BARYON will be composed of three quarks. With the broad variety of baryons and mesons the type of quark defines the final product. Next to the fact that various quarks have fractional charge the charm provides another identification. The charm can be “up (u)” with charge $u : +(2/3)e$ (rest ENERGY 360 MeV), electron charge MAGNITUDE: $|e| = 1.60217657 \times 10^{-19} C$, “down (d)” with charge $d : -(1/3)e$ (rest energy 360 MeV), “charmed (c)” with charge $c : +(2/3)e$ (rest energy 1500 MeV), “strange (s)” with charge $s : -(1/3)e$ (rest energy 540 MeV), “top (t)” with charge $t : +(2/3)e$ (rest energy 173,000 MeV), and “bottom (b)” with charge $b : +(2/3)e$ (rest energy 5000 MeV). The respective antiquarks: $\bar{u}$, $\bar{d}$, $\bar{c}$, $\bar{s}$, $\bar{t}$, $\bar{b}$, have opposing charge to the “regular” quark and identical rest energy. The quark charm principle was introduced by MURRAY GELL-MANN (1929–), for which he received the Nobel Prize in Physics, and GEORGE ZWEIG (1937–) in 1963 (see QUARK) (see Figure C.41).

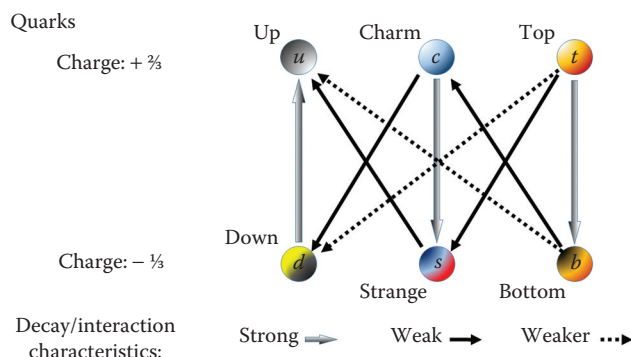


Figure C.41 Concept of “charm” pertaining to elementary particles, quarks in particular.

Châtelier–Braun principle

[chemical, thermodynamics] The principles of the changes to the chemical equilibrium introduced by the French chemist HENRY LOUIS LE CHÂTELIER (1850–1936) and independently by the German physicist and inventor Karl Ferdinand Braun (1850–1918). A system defined by the number of moles of the constituents of the medium, the pressure, and volume and temperature when subjected to change will affect the other parameters as well as the chemical balance of the constituents. In this situation an EXOTHERMIC REACTION will be forced to reverse its reaction when the system temperature is artificially increased, hence reducing the reaction constant. Alternatively, a temperature increase for an endothermic reaction will be encouraged to proceed in the direction that requires ENERGY, thus increasing the equilibrium reaction constant. Similarly changes in pressure or volume will force the chemical reaction in the direction that complies with the changing boundary conditions. This principle is also known as Le Châtelier principle, or as LE CHÂTELIER–BRAUN PRINCIPLE. Also referred to as CHÂTELIER–BRAUN INEQUALITIES, or Le Châtelier theorem.

Chebyshev, Pafnuty Lvovich [Пафну́тий Льво́вич Чебы́шёв] (1821–1894)

[computational, fluid dynamics] Mathematician from Russia. Chebyshev described several stochastic principles and introduced the basic concepts of number theory providing basic mathematical foundations, as well as PROBABILITY theory fundamentals.

Chebyshev inequality

[computational] In a PROBABILITY distribution mostly all values of a series of data are near the average value. Introduced by PAFNUTY CHEBYSHEV (1821–1894).

Chemical compound

[chemical] Pure substance composed of two or more ELEMENTS combined in a fixed and definite proportion by weight.

Chemical energy

[chemical, general, solid-state] Chemical reaction that delivers electrical ENERGY with electrical current in the form of free electrons. The electrochemical property is a direct result of the HALF-CELL phenomenon. This principle applies in particular to batteries. Alkaline batteries are producing nonreversible chemical reactions (disposable), whereas lithium-ion (i.e., LITHIUM) batteries (used in mobilephones and laptop computers) are rechargeable and the chemical reaction is reversed to the point where the electromotive force (V_{emf}) will be maintained for a long duration. The alkaline BATTERY is for instance based on the chemical reaction between zinc (Zn) and manganese dioxide (MnO_2), whereas the electrodes are potassium hydroxide (i.e., the alkaline). In the lithium-ion battery, lithium ions actually migrate between the CATHODE and the ANODE, hence producing a current externally; during the recharging process the ions are forced back by the applied external electric field. Other battery materials include lead-ACID, used in automobiles and hospital equipments. The charge carrying capability of a battery and the chemical reaction is expressed in ampere-hours, or charge multiplied by time. Another chemical energy application is in fuel cells, relying on OXIDATION of an ELECTROLYTE into free electrons, for example, hydrogen–oxygen and ALCOHOL and fossil fuel-based systems. The first battery (VOLTAIC PILE) was conceived by the Italian physicist ALESSANDRO VOLTA (1745–1827) in 1800 (see Figure C.42).

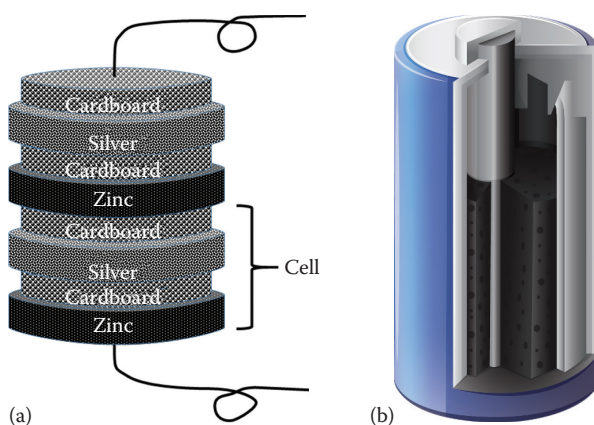


Figure C.42 (a) Chemical energy expressed by voltaic pile and (b) “dry cell.”

Chemical gradient

[biomedical] The relative difference in concentration over a DISTANCE within specific constituents of a mixture (GAS, LIQUID, or SOLID-STATE: n- and p-structures). One specific application is in the use of REVERSE osmosis in water purification (*also see* CHEMICAL POTENTIAL) (see Figure C.43).

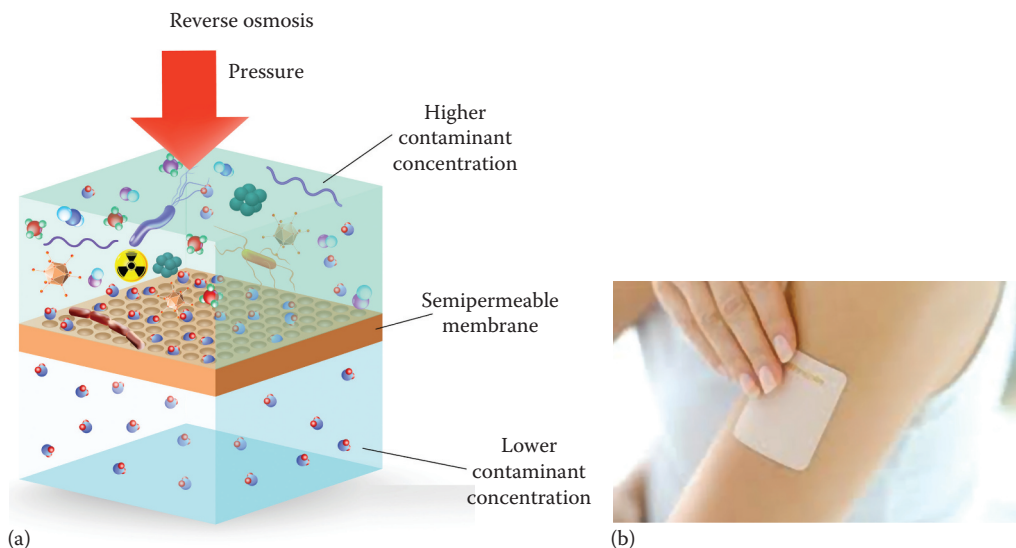


Figure C.43 (a) Chemical gradient in reverse osmosis water filtration. (b) Chemical gradient for nicotine patch used by individuals who are in the process of smoking cessation.

Chemical potential (μ_i)

[biomedical, thermodynamics] The partial derivative change in free ENERGY (F) per change in atomic and molecular (N) content, respectively, of the constituent $\mu_i = (\partial F / \partial N)_{T,V} = G(T, P, N) / N$ under constant temperature (T) and constant volume (V), incorporating the definition of the Gibbs free energy (G). Two systems in the same volume under identical conditions with the same i th constituent and in equilibrium will have the same chemical potential. There are four different types of chemical potential that can be discriminated: (1) thermodynamic chemical potential, (2) chemical potential, (3) electronic chemical potential, and (4) in relativistic concepts. The thermodynamic concept is used to describe the state in a system under certain conditions. For instance water will evaporate when the water temperature is above the boiling point, thus migrating from LIQUID to GAS state with an associated lower chemical potential in the gas/VAPOR state in comparison with the liquid state at that specific temperature. The rise in temperature will initiate the reordering from the higher to the lower potential. Similar change of state or equilibrium situations can be depicted for chemical reactions such as the ^{flame}OXIDATION of butane as described by the chemical reaction $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ with respective chemical potentials and the release of energy described by $E = 2\mu_{\text{gas}, C_4H_{10}} C_4H_{10} + 13\mu_{\text{gas}, O_2} O_2 - 8\mu_{\text{gas}, CO_2} CO_2 + 10\mu_{\text{gas}, H_2O} H_2O$ at the combustion temperature. The change in internal energy per change in unit state for each of the constituents i is written as $\mu_i(S, V, n) = (\partial U / \partial n_i)_{S, V, n}$, for $i = 1, 2, \dots, r$, where U is the internal energy, V the volume of the mixture, S the entropy of respective state, n the number of states, and r the total number of constituents. Chemical potential of SOLVENT with respect to constituent i is expressed as $\mu_i = \mu_{ii}(T, p) + RT \ln y_i$, where $\mu_{ii}(T, p) = \mu_i(T, p, y_1, y_2, \dots, y_r)$ or $\mu_{ii}(T, p_{ii}) = h_{ii}(T, p_{ii}) - Ts_{ii}(T, p_{ii})$ is the chemical potential of the pure solvent in the mixture at temperature T and pressure p , and y_i is the fractional component of each respective ingredient, with $\lim_i y_i \rightarrow 1$ yielding the solvent factor for constituent i and $R = N_A k = 8.3145 \text{ J/molK}$ is the universal gas constant, $N_A = 6.022 \times 10^{23} \text{ molecules/mol}$ the Avogadro number and $k = 1.38066 \times 10^{-23} \text{ J/K molecule}$ the Boltzmann constant. In this configuration the following

variable are used: $h_{ii}(T, p_{ii})$ the specific enthalpy of system ii and $s_{ii}(T, p_{ii})$ the respective specific entropy with p_{ii} the partial pressure of constituent i . Under chemical equilibrium at a GROUND STATE p_0 the chemical potential of a genuine constituent will equal the Gibbs free energy of reaction for that particular constituent, $\mu_{ii}(T, p_0) = g_{ii}(T, p_0)$. The latter can describe the conversion of CHEMICAL ENERGY into electrical energy for a BATTERY, for instance. The use in true chemical potential applies to biomedical PHYSICS and relates to the CHEMICAL GRADIENT. The chemical potential describes the difference in chemical concentration across a cellular MEMBRANE creating an electrical potential gradient according to the respective NERNST POTENTIAL for the constituents at either side of the membrane. The electronic chemical potential falls under theoretical chemistry as applied to density functional or energy functional theory. The electronic chemical potential is the functional partial derivative of the electrochemical density functional with respect to the system state defined as the electron density, which is expressed as $\mu_i(r) = [\partial E(\rho)/\partial \rho(r)]_{\rho=\rho_{\text{ref}}} = V_{\text{ext}}(r) + [\partial F(\rho)/\partial \rho(r)]_{\rho=\rho_{\text{ref}}}$, where ρ is the density functional ($E(\rho) = \int \rho(r)V(r)d^3r + F(\rho)$), where $F(\rho)$ is the universal functional which identifies the KE of the electrons in the CHEMICAL COMPOUND and $V_{\text{ext}}(\rho)$ is the combined influence of nuclear electrostatic potential and the electric influences of electric and magnetic fields external to the ATOM or molecule resulting from surrounding chemicals and outside influences, also referred to as the external potential). Since the electronic chemical potential is based on the electron density, this potential is equivalent to the electron negativity of the ATOM, as a MATTER of fact the sum of the electron affinity (EA) and the IONIZATION POTENTIAL (IP) for the atom. This commodity is also referred to as the Mulliken potential, $\mu_{\text{Mulliken}}(r) = -\chi_{\text{Mulliken}}(r) = -(\text{IP} + \text{EA})/2 = [\partial E(N)/\partial N]_{N=N_0}$. Last but not least, in relativistic physics the term chemical potential relates the states of FUNDAMENTAL PARTICLES analogous to the thermodynamic potential but with the following inherent and unique characteristics relativistically there will be no enthalpy of state for fermions and bosons, but each elementary PARTICLE contributes to the total internal energy of the system into which it is introduced or from which it escapes. The potential describes the tendency of ELEMENTARY PARTICLES to migrate out of energetic regions with higher chemical potential. The “relativistic” chemical potential is associated with the WAVE mechanical description of the elementary particles by the Boltzmann equation in QUANTUM physics and possesses a higher potential, which relates to a higher particle density. The elementary particle can be described as a gas of fermions and bosons. When just considering the fermions, the electrical potential is $\mu_F = kT \ln(\zeta) = kT \ln(e^{\epsilon_F/kT} - 1)$, where ζ is the fugacity, ϵ_F is the Fermi energy, or $\mu_F = (\partial E(N)/\partial N)_S = (\partial E_{\text{orbital}}(N)/\partial N)_S + (\partial E_{\text{electrostatic}}(N)/\partial N)_S$, where both terms represent the change in energy of the system if one particle is added under constant entropy (S). For an IDEAL GAS the chemical potential is linked to the PRESSURE (P) as $[\partial \mu_i(N)/\partial P]_T = V = RT/P$, or equivalently $[\partial(\mu_i/RT)/\partial \ln P]_T = 1$ (also see FERMI ENERGY).

Chemiluminescence

[biomedical, chemical, solid-state] Light produced as the result of a chemical reaction. The most well-known CHEMILUMINESCENCE reaction is oxidation–reduction, specifically produced during a fire. A more intricate oxidation–reduction reaction is the CHEMICAL ENERGY transfer that results in an excited SINGLET STATE, which has a limited lifetime and degrades with the emission of light. A strictly chemical reaction describing just such formation of a singlet state is in the reduction reaction of an amino-based derivative with a base and oxygen-based compound that can release the oxygen for OXIDATION, producing nitrogen and (high-energy) blue light. Other available mechanisms that produce light under a variety of ENERGY transfer principles are BIOLUMINESCENCE (e.g., firefly), ELECTROLUMINESCENCE (e.g., LIGHTNING), radioluminescence (e.g., scintillation), and thermoluminescence (every object with a temperature above ABSOLUTE ZERO kelvin emits light with a

wavelength range directly inversely proportional to the ABSOLUTE TEMPERATURE; glowing heating coil on electric stovetop or, indirectly, the incandescent lightbulb) (see [Figure C.44](#)).

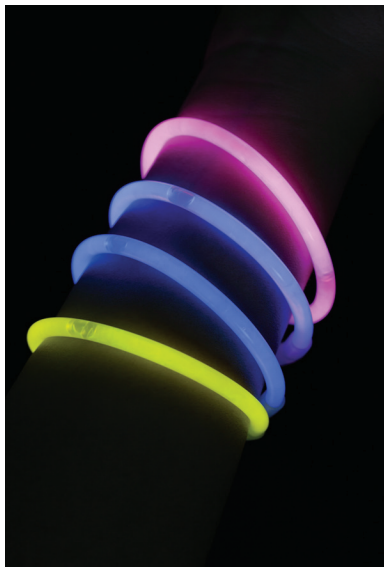


Figure C.44 Chemiluminescence example producing light in a “glow stick,” for instance, used during deep-sea diving. Also used as decorative jewelry.

Chézy, Antoine de (1718–1798)

[fluid dynamics] Engineer from France. In 1769 Chézy performed experiments on the FLOW RESISTANCE in open channels such as the Seine River near Paris and the Courpalet Canal. This information provided the heuristic Chézy formulas. The Chézy quantity (i.e., coefficient), C_{chezy} , varies from about $30 \text{ m}^{1/2}/\text{s}$ for small rough channels to $90 \text{ m}^{1/2}/\text{s}$ for large smooth channels (see [Figure C.45](#)).



Figure C.45 Antoine de Chézy (1718–1798).

Chézy’s formula, open channel

[fluid dynamics] Heuristic expression for FLOW velocity in an open canal. The flow velocity in an OPEN CHANNEL is defined as $v = C_{\text{chezy}} \sqrt{m \theta_{\text{incl}}}$, where m is the mean hydraulic depth, θ_{incl} the inclination ANGLE of the riverbanks, and C_{chezy} the Chézy’s flow velocity coefficient. The Chézy’s flow velocity

coefficient can be approximated by the formula derived by the Swiss engineers Emile-Oscar Ganguillet (1818–1894) and Wilhelm Rudolf Kutter (1818–1888) (GANGUILLET–KUTTER EQUATION, 1869): $C_{\text{chezy}} = [23 + (1/n) + (0.00155/\theta_{\text{incl}})] / [1 + [23 + (0.00155/\theta_{\text{incl}})](n/\sqrt{m})]$, where n defines the conditions of the surface of the WALL of the flow and is found listed in tables for specific materials (e.g., polished wood: $n = 0.010$ to 0.013 ; river with rocks imbedded in the shores and bottom as well as grass and growth: $n = 0.035$ to 0.05).

Chilton–Colburn j-factor for heat transfer

[fluid dynamics, thermodynamics] See COLBURN J-FACTOR, HEAT TRANSFER.

Chilton–Colburn j-factor for mass transfer

[fluid dynamics, mechanics, thermodynamics] See COLBURN J-FACTOR, MASS TRANSFER.

Chip

[electronics, solid-state] Silicon SEMICONDUCTOR crystal substrate designed to perform select electronic functions using N-TYPE and P-TYPE materials, also known as integrated circuit (see [Figure C.46](#)).



Figure C.46 Chip.

Chromaticity

[biomedical, chemical, optics] Definition of perceived COLOR space, also defined under CIE standards, based on the organization that has standardized the concept of color “Commission International de Illumination” (see [Figure C.47](#)).

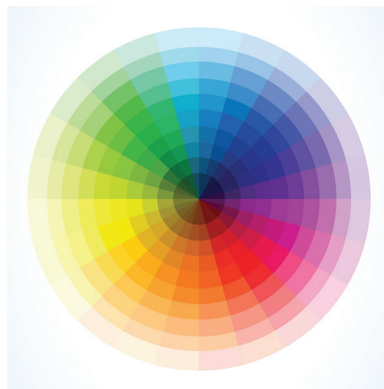


Figure C.47 Chromaticity color chart.

Chromatograph

[electronics, general, solid-state] Analytical device to assist in the analysis of the composition of media in a process called CHROMATOGRAPHY. Also used as gas-LIQUID chromatograph, or liquid-gas chromatograph, gas chromatograph, and gel permeation chromatography (see [Figure C.48](#)).



Figure C.48 Gas chromatograph equipment for analytical processing based on spectral attenuation profile of chemical constituents.

Chromatography

[electronics, general, solid-state] Analytical process designed to resolve the composing constituents of a mixture. Chromatography is applied to chemical analysis. The applications of chromatography range from analysis of petrochemical, environmental, pharmaceuticals, cosmetics (“fragrance”), food- (e.g., safety, flavor) and water quality, and in therapeutic diagnostics as well as for analysis of biological specimen submitted for instance during urine analysis or drawn BLOOD, next to forensics. Chemical chromatography uses the process of DIFFUSION when subjected to a bed of resin particles, with different diffusion coefficients for different SOLUTE molecule sizes. The resin is generally arranged in a column, analyzing the mobile PHASE of the respective components with high degree of RESOLUTION. The “steady-state” medium, affecting the separation process, is referred to as the stationary phase of the mixture. The separation process is arranged in a column. In GAS chromatography the mobile unit is in gas form. Gas chromatography is more popular for volatile components. The analysis relies on the optical spectral attenuation from transmitted light, providing specific representative absorption peaks at representative wavelengths (actually in chromatography one relies on the chromatography “wave numbers,” $k' = 1/\lambda$; note that the regular WAVE number is defined as $k = 2\pi/\lambda$). Different chromatography techniques are available for specific applications. Chromatography can define molecular chains and atomic ingredients. Different mechanisms of action involved in the chromatographic analysis are, for instance, ADSORPTION chromatography, affinity chromatography, ION-exchange chromatography, gel chromatography, and partition chromatography, each with its own mechanism of molecular separation. Specifically, the mechanisms described influence the retardation process associated with the respective DIFFUSION processes. For instance gel chromatography uses polyacrylamide and other types of gels to act as sieves. In affinity chromatography the use of a chemical matrix (for instance, a biomolecular matrix used to identify antigens or antibodies) provides a binding process used for separation. Specific analyses are available for the identification, for instance, of alkaloids, amino acids, nucleic acids, proteins, steroids, and vitamins.

Chromophore

[biomedical, general, optics] Dye constituent that provides the essence of COLOR of a molecular composite medium observed or measured with optical devices. The chromophore is either a separate molecule or a

component of a larger molecule and gains color when irradiated by a broad band LIGHT SOURCE, ideally WHITE LIGHT. The chromophore will absorb selected ranges of the source bandwidth, while the remaining spectral band(s) are re-emitted by means of shallow SCATTERING processes, which yields the visible color spectrum distribution (see [Figure C.49](#)).

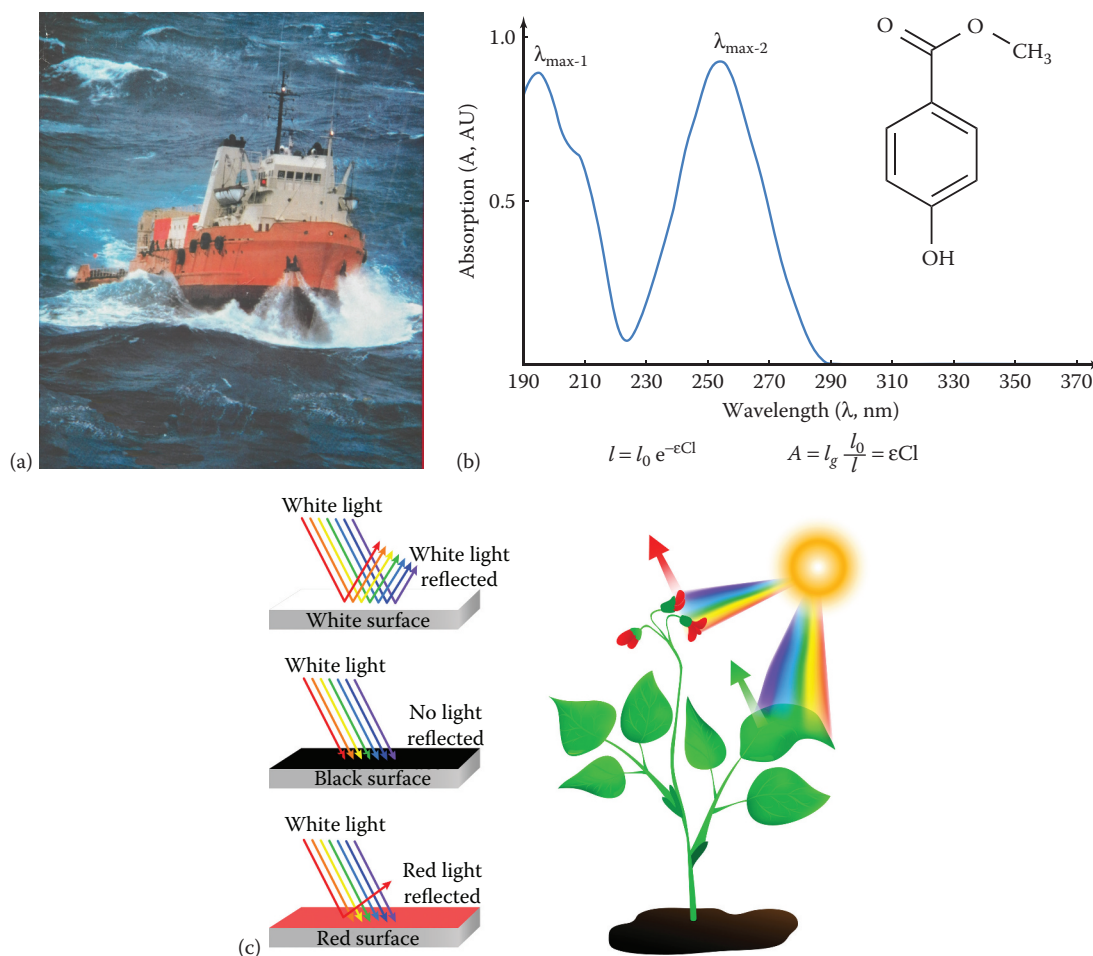


Figure C.49 (a) The orange color on the hull of the supply boat for oil rigs is the result of the choice in chromophores in the paint used, absorbing all but the “orange” color band of the incident white light. Whereas the “blue” color of the water is the result of Rayleigh scatter of the incident white light. (b) Absorption lines for the specific chromophores of the chemical compound paraben. (c) color of object based on backscattered/back-reflected portion of the incident white light; remaining part of spectrum is absorbed by the chromophores inclosed in the (surface) of the object. A black object inherently absorbs all incident light, a white object reflects all incident light. The full spectrum is perceived as white.

Chromosphere

[astronomy/astrophysics, geophysics] Solar layer above the PHOTOSPHERE, with a temperature greater than 4200 K, and a thickness for our SUN is approximately 2000 km, containing primarily helium and hydrogen. The chromosphere is best investigated during a full total eclipse, exposing just the chromosphere (see [Figure C.50](#)).

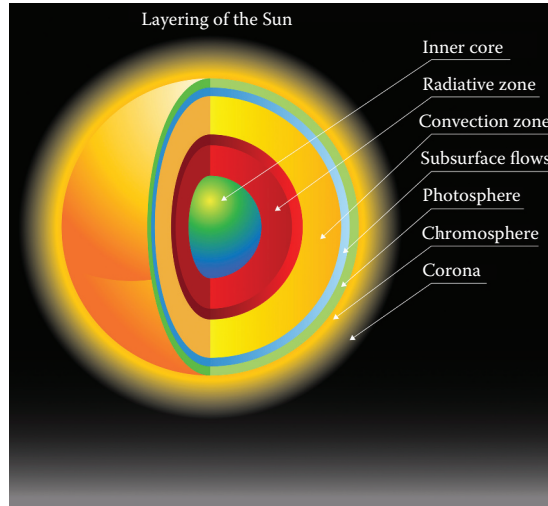


Figure C.50 Layers of the Sun, including the chromosphere.

CIE

[general, optics] Commission Internationale de l'Eclairage; The International Commission on Illumination; technical, scientific organization implementing standards and information exchange related to light, LUMINESCENCE, color and spectrophotometry, VISION and imaging as well as photobiology. CIE was founded in 1913 and is a nonprofit organization that acts independently providing advice on standardization. Although operating on a voluntary basis, CIE is recognized by ISO (International Organization for Standardization) as an international standardization institute. The committee is seated in Vienna, Austria.

CIE 1931 color space

[biomedical, general, optics] The definition of COLOR perception by the International Commission on Illumination (CIE) initially released in 1931. The CIE 1931 color space provides a mathematically definition of COLOR spaces associated with the virtual XYZ color space as introduced. In the color space, Y means brightness, Z is proportional to blue stimulation, and X is an interpreted representation of the RED sensitivity curve of the CONES of the HUMAN EYE. The XYZ color space is also referred to as the TRISTIMULUS VALUES. XYZ can be confused with red-green-blue (RGB) cone responses even if X and Z are roughly equivalent to RED and blue, respectively. However, in the CIE XYZ color space, these values are not equal or similar to the S, M, AND L RESPONSES OF THE HUMAN EYE, but can be considered derived values (*also see* VISION).

CIE color space

[general, optics] Graphical representation of the hues and radiance of COLOR in a three-dimensional space, defined in "brightness" (L), hue and chrome (a : red-green; b : yellow-blue), expressed in the CIE $L^*a^*b^*$ color space, yielding the three axes. This scientific analysis overcomes subjectivity. For instance, when analyzing the color of teeth by a dentist for reconstructive dental work the ambient light, or examination light color temperature, will influence the observations, as will the personal history for the observer (good night rest, etc.; color blindness). The CIE color analysis uses spectrophotometric instrumentation for NUMERICAL determination. The color representation in EUCLIDEAN SPACE is defined based on the respective

measurements and plotted according to the “E-value” as $E = \sqrt{(L^2 + b^2 + c^2)}$. In case only hue and SATURATION is displayed (two-dimensional graph), the space is defined as $\text{Cab} = \sqrt{(a^2 + b^2)}$ (see [Figure C.51](#)).

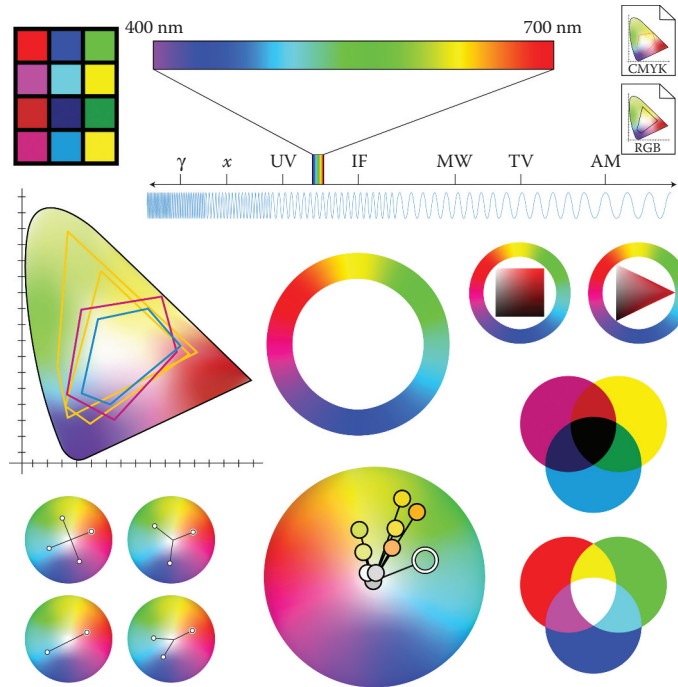


Figure C.51 CIE color charts and related tools for spectral identification and standardization.

Circulation

[fluid dynamics] The average FLOW velocity (i.e., wind velocity) on a path looping around the object in a flow pattern (e.g., WING), where flow against the path direction has a negative value and flow directions perpendicular to the path ($\vec{s}$) are not considered. Circulation is defined as the steady-state closed loop integral of the vorticity within the enclosed path. Where, the vorticity is the degree of “rotation” experienced in flow VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$) and time (t), which is the “curl” of the velocity at a given place. This will not consider initiation and termination processes. This yields for the circulation $\oint_C \vec{\omega}(\vec{r}, t) d\vec{s} = \oint_C \nabla \times \vec{v}(\vec{r}, t) d\vec{s}$. A flow at rest will have circulation zero. The WAKE of the flow in, for instance, the airstream around a wing has zero circulation, which also describes the VORTEX at the tip of the wake, assuming the loop integral is encompassing a large enough volume of space. The wake and wing-tip vortex have no viscous forces (no boundary layers) and hence the circulation is zero.

Circulation (Γ_{circ})

[fluid dynamics] The average FLUID FLOW velocity (i.e., wind velocity) on a path looping around the perturbation (i.e., WING), and can be represented as the closed loop integral of the VORTICITY ($\vec{\omega}(\vec{r}, t)$) within the enclosed path. $\Gamma_{\text{circ}} = \oint_C \vec{\omega}(\vec{r}, t) d\vec{r} = \oint_C \nabla \times \vec{v}(\vec{r}, t) d\vec{r}$. Where the vorticity is the degree of “rotation” experienced in flow VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$) and time (t), which is the “curl” of the velocity at a given place. The circulation at the boundary of the phenomena will be finite, the outer (i.e., horizontal) edges of the wings create a VORTEX that is at the edge of the WAKE.

Circulation function

[fluid dynamics] Arbitrarily closed loop over the FLOW around an object, $\oint_S [v_x(dx/ds) + v_y(dy/ds) + v_z(dz/ds)]ds$, in a Cartesian system (x, y, z) with flow velocity $\vec{v} = (v_x, v_y, v_z)$ over a loop S with path steps s tangential to the loop.

Circulatory system

[biomedical, fluid dynamics, general] BLOOD flow loop in a biological system; HEART, arteries, arterioles, capillaries, venules, veins, and back to hearts. The circulatory system has an oscillatory component (induced by the pumping rhythm of the heart) on the arterial side that dampens the AMPLITUDE (both velocity and pressure) in the growing impedance with reduction in FLOW lumen associated with increasing number of branching vessels. The circulatory system is defined by CONSERVATION OF MASS. In addition to the pumping mechanism of the heart, the veins have a flow mechanism that is supported by encapsulation from skeletal muscles. The SKELETAL MUSCLE function is important, especially when considering that a large number of people will faint when standing perfectly still for extended periods of time. An easy exercise to maintain CIRCULATION in the veins of the LEG is to periodically flex and release the leg muscles (see [Figure C.52](#)).

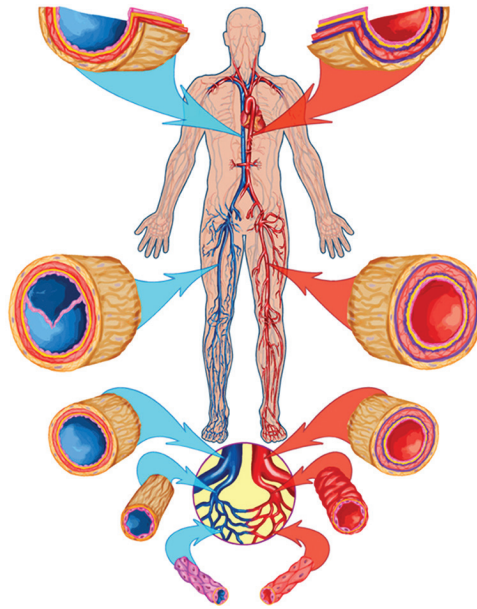


Figure C.52 Blood circulation diagram. Venous blood in blue and arterial (oxygen rich blood) blood in red.

Clapeyron, Benoît Paul Émile (1799–1864)

[thermodynamics] Physicist and engineer from France. Clapeyron made several recommendations for thermodynamics and defined many conditions as a pioneer in the new field of thermodynamics. Clapeyron

defined the two-phase mixture, for instance, steam and boiling water (*also see* CLAUSIUS–CLAPEYRON RELATION) (see [Figure C.53](#)).



Figure C.53 Benoît Paul Émile Clapeyron (1799–1864).

Clausius, Rudolf Julius Emanuel (1822–1888)

[general, mechanics, thermodynamics] German physicist and scientist. Clausius' father was a contemporary of JAMES PRESCOTT JOULE (1818–1889) and LORD KELVIN (a.k.a. WILLIAM THOMSON: 1824–1907), while he himself was a contemporary of NICOLAS LÉONARD SADI CARNOT (1796–1832). The work of Carnot inspired Clausius to formulate his own interpretation of HEAT TRANSFER, different from that expressed by Lord Kelvin in the SECOND LAW OF THERMODYNAMICS as: There is no single isolated process that results in the transfer of heat from a body at low temperature to a body at higher temperature. Meaning that there are multiple processes at a stage to accomplish one goal, in the refrigeration this equates to work performed with losses due to the work itself (generating heat of its own), while transferring heat against a gradient. In 1865 Clausius introduced the concept of ENTROPY (see [Figure C.54](#)).



Figure C.54 Rudolf Julius Emanuel Clausius (baptized name: Rudolf Gottlieb; 1822–1888).

Clausius–Clapeyron relation

[thermodynamics] $dP/d\tau_T = L/\tau_T(\rho_V^{-1} - \rho_L^{-1}) = L/\tau_T \Delta v_a$, where P is the VAPOR PRESSURE, τ_T the temperature, ρ_V the density of the vapor phase, ρ_L the density of the LIQUID phase, L the LATENT HEAT OF VAPORIZATION ($L \equiv \tau_T(S_g - S_\ell) = dQ$, where S_i the entropy of the GAS and liquid phases, respectively, and dQ the heat added to the system), and v_a the volume occupied by one ATOM or molecule of the constituent. Note the derivative is not simply as in the EQUATION OF STATE for the gas, but assumes the gas and liquid to coexist. Generally we can assume that the GAS PHASE of an atomic gas (v_{ag}) occupies a greater volume than in the liquid phase (v_{al}) and $\Delta v_a = v_{ag} - v_{al} \cong v_{ag} = V_g/N_g$, with V_g the gas volume of the constituent and N_g the number of molecules or atoms in the gas state, respectively.

Climatology

[energy, fluid dynamics, general, geophysics] Field of PHYSICS dealing with physical phenomena in the lower part of EARTH'S ATMOSPHERE directly related to the weather and providing warnings for people in the path of inclement weather (see [Figure C.55](#)).

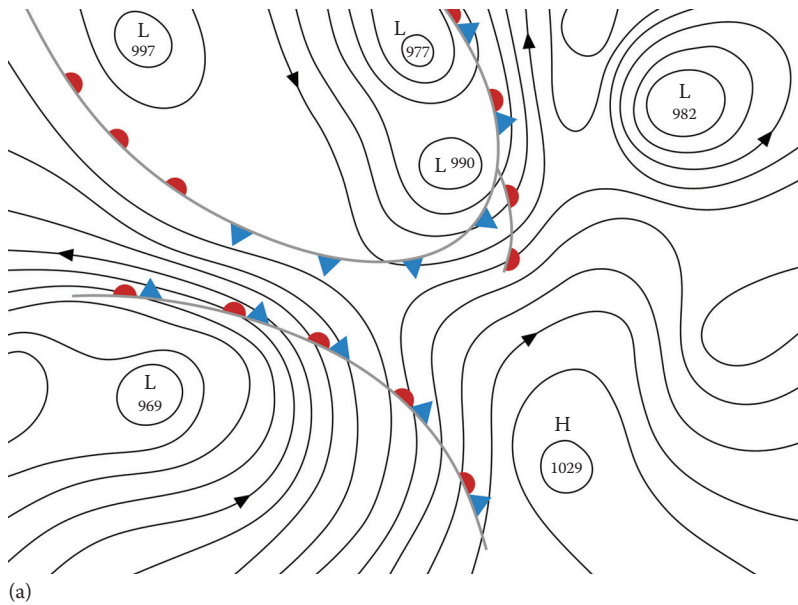


Figure C.55 Climatological tools: (a) cold and warm front migration in three dimensions

(Continued)

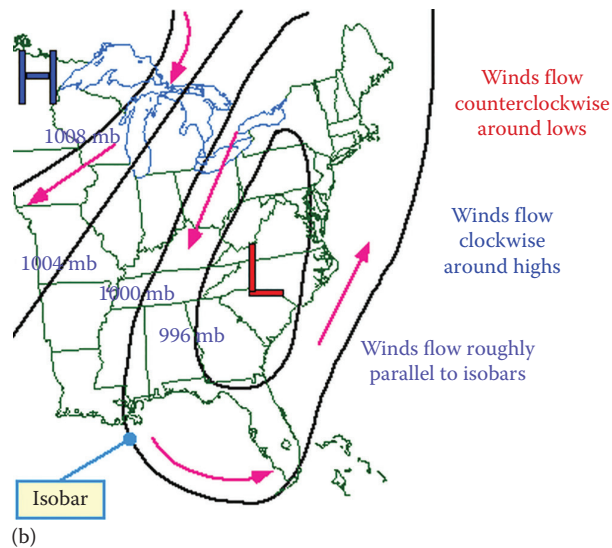


Figure C.55 (Continued) Climatological tools: (b) drawing of isobars on a section of the global map. (Courtesy of University of Illinois, Department of Atmospheric Sciences, IL.) and (c) mobile meteorological station. (Courtesy of CBS KCNC-TV Denver, CO.)

C/M Ratio

[electromagnetism] Expression used in frequency modulation synthesis, where M is the modulator frequency and C the CARRIER frequency. Frequency modulation synthesis is a tool used in spectral analysis.

Coalsack Nebula

[astrophysics] Dark “cloud” observed in the band of the Milky Way galaxy, dating back to millennia, documented by the Inca’s and early European observers (documented in 1499 by Spanish explorer Vicente Yáñez Pinzón [1462–1514]), next to Australian Aborigines approximately 40,000 years ago (WALL drawings). Recent discoveries show that the interstellar “dust” cloud of particles is so dense that it blocks virtually all background light (blocks better than 90%) at an azimuth in the “southern” portion of the MILKY WAY.

The COALSACK NEBULA is located between 610 and 790 light-years DISTANCE, in the constellation Crux (“The Southern Cross”) and spans approximately 50 light-years at its widest EXPANSION. The Coalsack Nebula is also featured in the original science fiction television series *Star Trek*, the “Immunity Syndrome” episode (1968). The configuration of the Coalsack Nebula can be derived from the equations on galactic light SCATTERING introduced by KARL SCHWARZSCHILD (1873–1916), based on cumulative information acquired over the years, and most recently by observations made by the MPG/ESO 2.2-m TELESCOPE at European Southern Observatory’s La Silla Observatory in Chile, which is one of the driest areas in the world as well as extremely remote, located 150 km northeast of La Serena on the periphery of the Atacama Desert in Chile. The dust spread-out in the nebula provides significant attenuation for transmitted light from remote stars. The dark spot has been known and described for a considerable time. The aboriginal population of Australia described it as the head of an emu. The Incas in South America circulated the story that it was the god Ataguchu who kicked a hole in the band of stars (now known as the Milky Way) in a fit of anger (see Figure C.56).



Figure C.56 “Coalsack” in the constellation Crux, depicted by the dark “hole.” The Crux constellation is up and to the right, in the shape of a cross. (Courtesy of Dr. Poshak Gandhi.)

Coefficient of drag

[fluid dynamics, mechanics] Coefficient defining the influence of the retarding effects resulting from FRICTION and VISCOSITY with respect to a body moving through a FLUID. The coefficient of drag (D_{flow}) can be found in tables for fluids and surface conditions and is correlated to the DRAG force (F_{drag}) as $F_{\text{drag}} = D_{\text{flow}} \rho A (v^2/2)$, with v the velocity of the object in the fluid (e.g., water, AIR), ρ the fluid density, and A the effective cross-sectional area of the object in MOTION.

Coefficient of friction ($C_f = \sigma_s / (1/2) \rho v^2$)

[fluid dynamics, mechanics] Surface SHEAR STRESS expressed as dimensionless number defined by the STRESS over the KINETIC ENERGY density, where ρ the DENSITY of the FLUID, v VELOCITY, and σ_s the stress. Also defined as the ratio of SHEAR STRESS (σ_s) with respect to NORMAL STRESS (σ_n), $C_f = \sigma_s / \sigma_n$.

Coefficient of friction, kinetic (μ_{kin})

[mechanics] The ratio of the FRICTION force (F_f) to the NORMAL FORCE ($F_n = mg \cos(\theta)$), where θ is the ANGLE with the normal to the surface) for an object in MOTION. An object being dragged over a surface will experience KINETIC FRICTION, such as a sled sliding down a snowy hill (see Figure C.57).



Figure C.57 Sliding down a ski slope with limited kinetic friction.

Coefficient of friction, rolling (μ_{rol})

[mechanics] The ratio of the FRICTION force (F_f) to the NORMAL FORCE ($F_n = mg \cos(\theta)$), where θ is the ANGLE with the normal to the surface) for an object in MOTION. The friction force needs to be overcome to maintain uniform rolling motion at uniform VELOCITY (see Figure C.58).

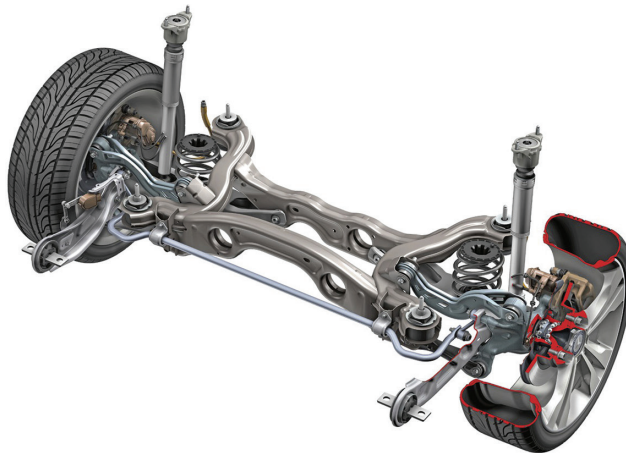


Figure C.58 Deformation of an automobile tire resulting in rolling friction. Rear axle with tire cut open illustrating room for deformation. (Courtesy Daimler AG, Stuttgart, Germany.)

Coefficient of friction, static (μ_{stat})

[mechanics] The ratio of the FRICTION force (F_f) to the NORMAL FORCE ($F_n = mg \cos(\theta)$), where θ is the ANGLE with the normal to the surface) for an object at rest. This would apply to an automobile tire on the

road under normal steady-state velocity and acceleration without slip. Also a box resting on a slope will experience static friction (see [Figure C.59](#)).

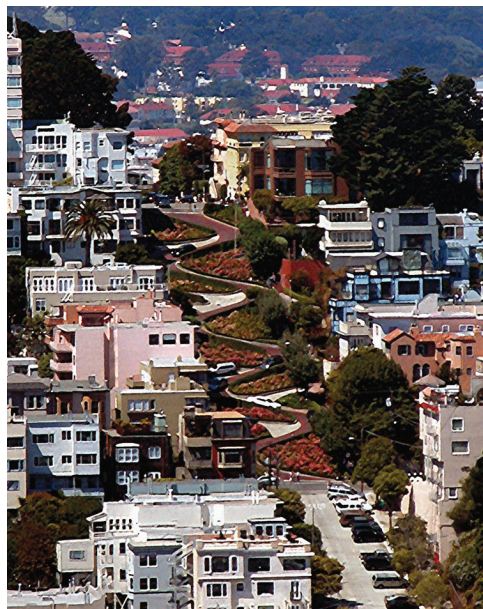


Figure C.59 Person standing in fixed location on Lombard Street incline in San Francisco due to static friction.

Coefficient of kinetic friction

[mechanics] See COEFFICIENT OF FRICTION, KINETIC.

Coefficient of kinetic friction (μ_K)

[general, mechanics] Relation between the resistive force (F_K) and NORMAL FORCE (F_N) for a body in uniform MOTION while experiencing a force with a component parallel to the free surface the body rests on, $F_K = \mu_K F_N$.

Coefficient of rolling friction

[mechanics] See COEFFICIENT OF FRICTION, ROLLING.

Coefficient of rolling friction (μ_R)

[general] FRICTION coefficient for the dissipative force resulting from deformations observed, for instance, for a tire on the road surface or a waltz rolling out asphalt (see COEFFICIENT OF FRICTION, ROLLING).

Coefficient of static friction

[mechanics] See COEFFICIENT OF FRICTION, STATIC.

Coefficient of static friction (μ_S)

[general, mechanics] Relation between the resistive force (F_S) and NORMAL FORCE (F_N) for a body at rest while experiencing a force with a component parallel to the free surface the body rests on. As long as the parallel component of the force does not exceed the frictional force ($F_f = \mu_s F_N$) the body will remain at rest, $F_S \leq \mu_s F_N$.

Cohesion

[general, solid-state, thermodynamics] Binding force between molecules of a substance. Contrast to ADHESION, which applies to MACROSCOPIC entities.

Colburn j-factor, heat transfer ($j_H = (h_0/c_p G_m)_s (c_p \eta / \kappa)_s^{2/3} (\eta_w / \eta)_s^{0.14} = \text{StPr}^{2/3}$)

[fluid dynamics, thermodynamics] Dimensionless number illustrating the ratio of heat transfer to crossflow REYNOLDS NUMBER, where s describes the conditions of FLOW on the shell or WALL, h_0 the film heat-transfer coefficient, $G_m = \dot{W}_s / S_m$ the mass velocity, specifically pertaining to the free flow area bridging adjacent tubes, with $\dot{W}_s$ the mass flow rate at the wall and S_m the minimum free flow through either crossflow areas, c_p the SPECIFIC HEAT under constant pressure, $c_{p,\eta}$ the specific heat under constant flow at wall FRICTION, κ the THERMAL CONDUCTIVITY, η the VISCOSITY of the FLUID, η_w the viscosity at the wall, St the Stanton number, and Pr the Prandtl number. Sometimes also referred to as CHILTON–COLBURN J-FACTOR FOR HEAT TRANSFER.

Colburn j-factor, mass transfer ($j_m = \text{St}_m \text{Sc}^{2/3}$)

[fluid dynamics, mechanics, thermodynamics] $j_m = (\kappa_m / v)(\eta / \rho D_{\text{dif}}) = \text{St}_m \text{Sc}^{2/3}$, dimensionless number representing the ratio of FRICTION forces to DIFFUSION forces, where $\kappa_m = \text{mole} / \mathcal{A} \times t \times [a]$ is the mass transfer coefficient, with $\mathcal{A}$ the area, t time, $[a]$ the concentration of constituent “ a ,” v the velocity of mass transport (either FLOW or diffusion), D_{dif} diffusion coefficient, ρ the density, St_m the Stanton mass transfer number, and Sc the Schmidt number. Sometimes also referred to as CHILTON–COLBURN J-FACTOR FOR MASS TRANSFER. In case there is transfer of momentum, the Colburn mass transfer j-factor will be equal to the Colburn HEAT TRANSFER j-factor, which is only the case when there is no FORM DRAG. The conditions of no form drag apply under certain specific circumstances to flat plates and inside straight conduits.

Colliding black holes

[astrophysics, relativistic] Generate ripples in time referenced as gravitational space-time perturbations (*see* TIME PERTURBATION, COLLIDING BLACK HOLES; GRAVITATIONAL WAVE; and EINSTEIN EQUATIONS).

Colloid osmotic pressure

[biomedical, chemical, thermodynamics] The osmotic pressure of a SOLUTION as if the PARTICLE solution would be a GAS with the same volume and temperature as the solution. The osmotic pressure can be expressed by the IDEAL GAS LAW, $\Pi_{\text{osm}} = nRT/V = [C]RT$, where $R = 8.135 \text{ J/molK}$ is the gas constant, T the local temperature in Kelvin, n is the number of moles of solution, and $[C]$ the concentration (*also see* STARLING’S LAW and VAN’T HOFF LAW).

Color

[computational, energy, general, nuclear, quantum, relativistic, solid-state, thermodynamics] Also referenced as color force. This label is associated with the FOUR FORCES. Designation in the STRONG NUCLEAR force that acts on a property defined as “color,” which has three states: r, g, b (also referenced as: RED, green, and blue). This in comparison with the ELECTROMAGNETIC FORCES that act on charges (positive and negative) and the GRAVITATIONAL FORCE which acts on mass. Basic constituents red, green, and blue can form all other colors visible to the HUMAN EYE. Depending on the mechanism the colors can be additive (e.g., light, where all three form WHITE LIGHT) or canceling or subtractive (e.g., paint; a mixture of all three colors yields black).

Comet

[astronomy/astrophysics, mechanics] Celestial object consisting of frozen medium and solids, leaving a trail of GAS and charged particles, the comet’s tail. The tail emanates from the head, or coma of the comet.

The principal content of the comet is supposedly found in the NUCLEUS of the coma. Note that the tail of charged particles has a different ANGLE to the comet's trajectory than the VAPOR cloud tail; forming two tails. This is different from an ASTEROID, which has no tail and consists of solids only. One of the more noted comets is HALLEY's COMET, last seen in 1986. Halley's comet (initially Comet 1982i; renamed Comet 1986III) moves on its orbit around the SUN, traveling to the edges of our SOLAR SYSTEM, every 75–76 years, depending on our own position with respect to the observation in our orbit around the Sun. Another notable comet is Hale–Bopp (astronomy nomenclature: Comet C/1995 O1, “discovered” in 1995), which has been described dating back to millennia and has a period of 2537 years, and Hyakutake. So far a total of 10 comets have been identified in our solar system. The direction of the gas/vapor tail is indicative of the SOLAR WIND. Comets are considered to be essential constituents of the formation of our solar system; hence are bound to carry information about the history of the creation of the solar system (see [Figure C.60](#)).



Figure C.60 A comet.

Communicating vessels

[general, fluid dynamics] The FLUID surface of open vessel that are connected by free-flowing passages will be at equal level under equilibrium, independent of the shape and size of the respective vessels (see [Figure C.61](#)).

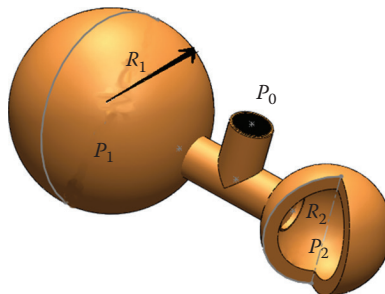


Figure C.61 Communicating vessels.

Compliance

[biomedical, general, mechanics] (C_{compl}) indication of elastic nature of a material or composition (e.g., amalgamation of multiple components such as multilayer or mash/webbing and “solid” filler). The phenomenon is in particular applicable for an distensible tube, in which case the tube expands with increasing

applied PRESSURE (P), making the compliance a direct function of the change in VOLUME (V) as a result of the change in pressure: $C_{\text{compl}} = \Delta V / \Delta P$.

Compressibility factor (Z_{com})

[thermodynamics] Parameter indicating the deviation from the IDEAL GAS LAW, and ideal gas conditions. The compressibility factor, $Z_{\text{com}} = PV/nRT$, will equal 1 for an IDEAL GAS (*also see* VAN DER WAALS EQUATION OF STATE).

Compressibility of gas in fluid

[fluid dynamics] The rate of change in volume of a dissolved GAS under compression of the solvent FLUID: $B_g = \gamma P / \alpha$, with P the externally applied pressure (in Pascal), $\gamma = c_p / c_v$ the ratio of the specific heats of the gas, and α the volume fraction of the undissolved gasses.

Compression waves

[acoustics, atomic, biomedical, fluid dynamics, geophysics] Transfer WAVE in liquids, solids, and gasses. For compression waves in fluids see both ACOUSTICS and SOUND.

Compression wave, propagation

[acoustics, atomic, biomedical, fluid dynamics, geophysics] Any solid, LIQUID, or GAS can be compressed by an external force, resulting in relaxation based on the bulk modulus, which culminates in a (damped-) OSCILLATION in the form of a longitudinal elastic compression wave. This compression wave can be at the atomic level. In fluids the medium responds differently than in solids and the WAVE is called an acoustic wave. In general the compression oscillation mode is also the direction of propagation. The oscillatory medium is identified by alternating rarefactions and condensations (*also see* LAMB WAVE). The speed of propagation (v) in sea water is a direct function of depth, salinity, and temperature and can be defined in first-order approximation as $v = \sqrt{B/\rho}$, where B is the bulk modulus and ρ the local density. The propagation velocity at the water surface at certain wavelength and temperature is approximately 1.4×10^3 m/s, while at a depth of 5 km this becomes 1.5×10^3 m/s while an increase of 1°C results in an increase of 3.7 m/s and an increase in salinity by 1% increases the speed of wave propagation by 1.2 m/s. In comparison the speed of propagation in solids is defined by $v = \sqrt{Y/\rho}$, where Y is the Young's modulus and ρ the local density. For EARTHQUAKE COMPRESSION, wave propagation velocity is 1.3×10^4 m/s, approximately 10× greater. Compression waves are also used in ULTRASONIC IMAGING, relying on the differences in speed of propagation or modulus of tissue constituents in organs (see Figure C.62).

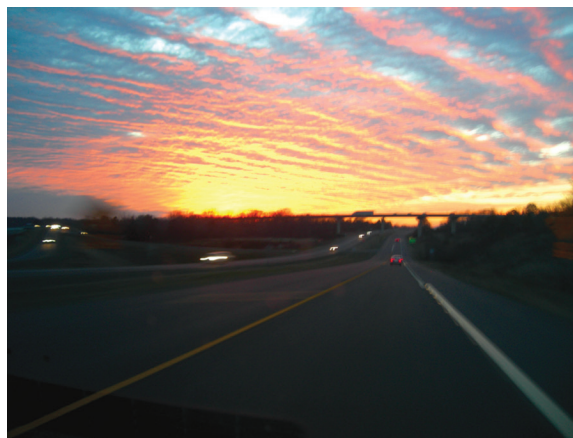


Figure C.62 Example of atmospheric compression wave. The expansion (lowering the local pressure) in a linear direction forms condensation (cooling during expansion), expressed by parallel rows of clouds.

Compton, Arthur Holly (1892–1962)

[atomic, biomedical, nuclear] Scientist from the United States who provided empirical proof of the momentum as well as ENERGY phenomena associated with ELECTROMAGNETIC RADIATION next to that of particles, published in 1922. Based on the energy observations and the prevailing CONSERVATION LAWS the energy loss of a colliding electrons generates a PHOTON with the energy balance at hand as described by the COMPTON EFFECT. Arthur Compton received the Nobel Prize in Physics in 1927 for his description of the ATOMIC ENERGY explained by the Compton effect (see [Figure C.63](#)).



Figure C.63 Arthur Holly Compton (1892–1962). (Courtesy of Noble Foundation, Stockholm, Sweden.)

Compton effect

[atomic, biomedical, condensed matter, energy, nuclear] Description of the ENERGY loss of a PHOTON involved in a collision with free electrons. The conservation of momentum forms the basis of the determination of the wavelength of the re-emitted photons as follows: $\vec{p}_{i,\text{photon}} = \vec{p}_{\text{elec}} + \vec{p}_{s,\text{photon}}$, where $p_{i,\text{photon}} = h/\lambda$ is the momentum of the incident photon ($h = 6.6260755 \times 10^{-34}$ Js the Planck's constant, λ the wavelength of the incident ELECTROMAGNETIC RADIATION with energy $E_{i,\text{photon}} = h\nu$, ν the frequency of the RADIATION), the momentum of the scattered photon $p_{s,\text{photon}}$, with momentum of the electron as $p_{\text{elec}} = m_e v$ with rest energy: $E_{\text{elec}} = m_e c^2$, however the electron needs to be considered in relativistic terms which yields $E_{\text{elec}}^2 = p_e^2 c^2 + m_e^2 c^4$, based on the CONSERVATION OF ENERGY: $E_{i,\text{photon}} + m_e c^2 = E_{s,\text{photon}} + E_{\text{elec}}$. The increase in wavelength from the incident photon with wavelength λ_i to the emitted photon with wavelength λ_s is due to the collision loss, which can be written as $\Delta\lambda = \lambda_i - \lambda_s = h/m_e c (1 - \cos\theta)$, where θ represents the ANGLE OF SCATTERING with respect to the incident direction and $\Delta\lambda$ represents the COMPTON WAVELENGTH (see [Figure C.64](#)).

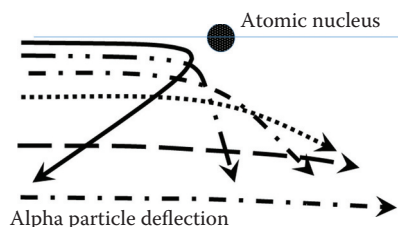


Figure C.64 Compton effect. The angular deflection of a beam of alpha particles nearing an atomic nucleus.

Compton scattering

[atomic, biomedical, condensed matter, energy, nuclear] See COMPTON EFFECT.

Compton wavelength

[atomic, biomedical, condensed matter, energy, nuclear] The increase in wavelength from the incident PHOTON with wavelength λ_i to the emitted photon with wavelength λ_s is due to the collision loss, which can be written as $\Delta\lambda = \lambda_i - \lambda_s = h/m_e c (1 - \cos\theta)$, where θ represents the ANGLE OF SCATTERING with respect to the incident direction. In molecular PHYSICS the interaction between two protons with the release of a PION ("π") (i.e., π-MESON), with mass m_π , is represented by the potential equation: $V = \vec{\tau}_a \cdot \vec{\tau}_b g_\pi^2 (m_\pi/2M) [(1/3)(e^{-\mu_c r}/r)(\vec{\sigma}_a \cdot \vec{\sigma}_b) + [(1/3) + (1/\mu_c r) + (1/\mu_c^2 r^2)](e^{-\mu_c r}/r)S_{ab}]$, where $1/\mu_c = \hbar/m_\pi c = 1.4$ fm is the pion Compton wavelength ($\sqrt{G\pi^2/\hbar c}$ is the pion–nucleon coupling constant, $\hbar = h/2\pi$, where $h = 6.6260 \times 10^{-16}$ Js is Planck's constant), $\vec{\sigma}_a$ and $\vec{\sigma}_b$ are the PAULI SPIN MATRICES for the respective nucleons a and b , $\vec{\tau}_a$ and $\vec{\tau}_b$ are the respective isospin matrix in 2×2 format for NUCLEON a and b , r the nucleonic interspacing DISTANCE, c the speed of light, g_π the pion ENERGY, and $S_{ab} = 3(\vec{\sigma}_a \cdot \vec{r})(\vec{\sigma}_b \cdot \vec{r}) - (\vec{\sigma}_a \cdot \vec{\sigma}_b)$ the TENSOR operator; the intrinsic SPIN can also be characterized as $S^{(a)} = \vec{\sigma}_a \hbar/2$.

Computational fluid dynamics (CFD)

[biomedical, computational, fluid dynamics, thermodynamics] FLUID DYNAMICS problems solved by advanced and extensive mathematical analysis. Early on (prior to computers) NUMERICAL solutions were attempted by hand dating back to the eighteenth century, referred to as theoretical fluid dynamics, in contrast to experimental fluid dynamics. The intricacy of the theoretical approach extended to complex and extensive problem statements with lengthy periods (e.g., months) spent on working out the solutions. More recent examples are the work by LEWIS FRY RICHARDSON (1881–1953) in 1910 on Laplace equations for HEAT TRANSFER and RICHARD COURANT (1888–1972), KURT OTTO FRIEDRICHS (1901–1982), and HANS LEWY (1904–1988) in 1928 for their work on hyperbolic partial differential equations. The culmination of these efforts came to flourish with the more widespread availability of computers in the 1960s and 1970s shown by the 1973 work of W. Roger Briley (twentieth century) and H. McDonald (twentieth century), and the work of Richard M. Beam (twentieth century) and R.F. Warming (twentieth century) in 1976 and 1978 solving Navier–Stokes and Euler algorithms (see Figure C.65).

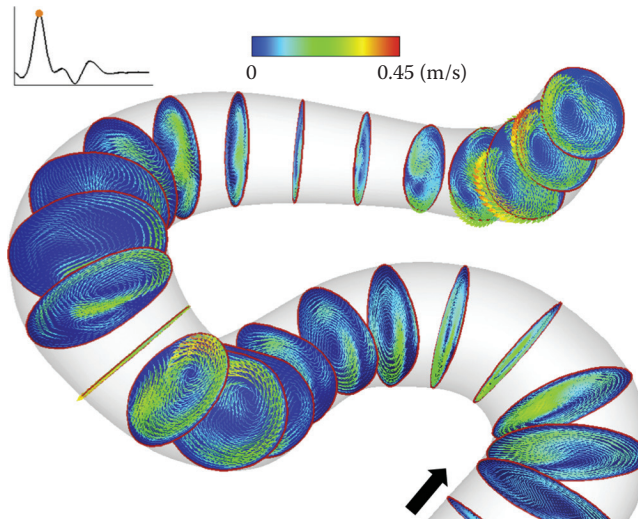


Figure C.65 A computational analysis of fluid flow in a tube.

Condensation number ($Co = g\rho^2 \Delta H_{\text{vap}} L^3 / \kappa \eta \Delta T$)

[thermodynamics] The ratio of molecular condensation on a surface to the total number of molecules in contact with the surface, where ΔH_{vap} is the LATENT HEAT OF VAPORIZATION, g GRAVITATIONAL ACCELERATION, L the characteristic length, ΔT temperature gradient, κ the THERMAL CONDUCTIVITY (Kappa), η VISCOSITY, and ρ the density.

C

Condenser

[electromagnetism, general] Old terminology for CAPACITOR, a device that can store ELECTRIC CHARGE.

Conduction band

[atomic, electronics, general] Under the influence of an external FORCE (e.g., ELECTRIC OR KINETIC), ELECTRONS can be moved to a higher ENERGY ORBIT, removed from the VALENCE BAND (with low BINDING ENERGY) to an ENERGY configuration that allows the electron to move away from the host ATOM'S NUCLEAR BINDING FORCE as a FREE ELECTRON. The energy configuration is referenced as the conduction band. Under room TEMPERATURE ($\sim 300\text{ K}$) the kinetic energy of electrons is approximately $KE = 0.026\text{ eV} \approx 4.1 \times 10^{-21}\text{ J}$. In comparison the gap energy (energy gap between valance band and conduction band) for a SEMICONDUCTOR such as germanium or silicon is approximately 1.1 eV , whereas in common CONDUCTORS, such as IRON and copper for instance, the conduction band overlaps the valence band, allowing electrons to move freely between neighboring copper atoms. When the THERMAL ENERGY can bring the VALENCE electron in the conduction band the phenomenon of ELECTRICAL CONDUCTION is enabled and an electric CURRENT can be established.

Conductor

[atomic, general] Materials made of ELEMENTS with specific ELECTRON configuration. An ATOM has the electrons arranged according to the BOHR ATOMIC MODEL with electrons in specific allowed ENERGY LEVELS or ORBIT SHELLS. In comparison with either INSULATOR or SEMICONDUCTOR the electron configuration is more energetic than in these two. In an INSULATOR the CONDUCTION BAND containing free electrons is unpopulated and separated by a FORBIDDEN GAP from the VALENCE BAND, whereas in conductor configuration the valence band is overlapping the conduction band, hence populating the conduction mechanism of action with free electrons.

Cones

[biomedical, chemical, optics] Anatomical feature in the EYE responsible for the electrochemical conversion of ELECTROMAGNETIC RADIATION in the PERCEPTION of three elementary colors that in combination with relative intensity will generate virtually infinite number of COLOR combinations. The various color pattern

definitions are, for instance, defined by the CIE system and described in greater detail under CHROMATICITY (see Figure C.66).

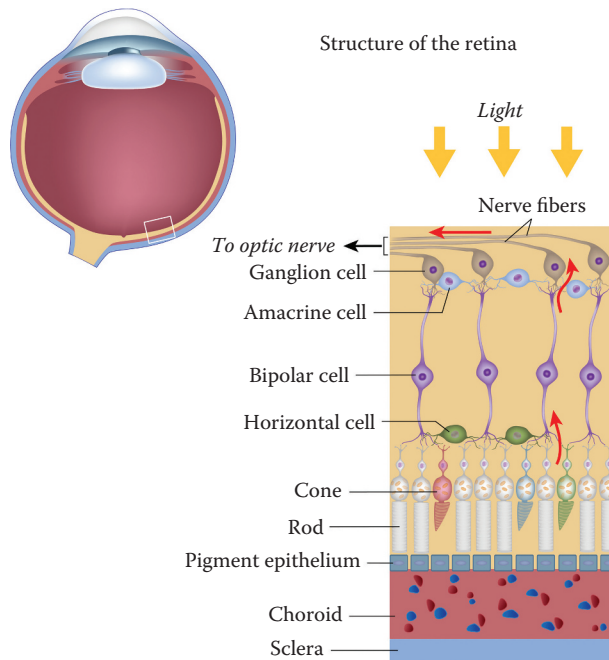


Figure C.66 Cones (color vision) and rods (radiance vision) in the retina of the eye.

Conservation laws

[atomic, general, thermodynamics] The following conservation principles/laws can be distinguished: CONSERVATION OF ANGULAR MOMENTUM, CONSERVATION of atomic nuclei, conservation of BARYONS, conservation of leptons, CONSERVATION OF CHARGE, conservation of current, CONSERVATION OF ELECTROMAGNETIC ENERGY, CONSERVATION OF ENERGY, CONSERVATION OF LINEAR MOMENTUM, CONSERVATION OF MASS, CONSERVATION OF MASS–ENERGY, conservation of MECHANICAL ENERGY, and conservation of momentum. Each conservation principle will be outlined at the respective location.

Conservation of angular momentum

[fluid dynamics, general, nuclear] The angular momentum is the product of the ANGULAR VELOCITY (ω) and the moment of INERTIA (I_{inertia}) of the object ($L = I_{\text{inertia}}\omega$), when no external forces are involved the TOTAL ANGULAR MOMENTUM of a system will be conserved. When a rotating system disintegrates (without exchange of ENERGY), the sum of the angular momentum as vectors will combine to provide the same angular momentum as for the initial structure. Conservation of angular momentum also applies to nuclear and atomic transitions, setting boundary conditions and selection rules for transitions, in direct combination with CONSERVATION OF ENERGY (see Figure C.67).

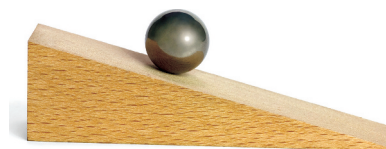


Figure C.67 Conservation of energy (conversion of potential energy to kinetic energy) and conservation of angular momentum illustrated by ball rolling down incline, which will continue its rolling path when a level plane is reached.

Conservation of charge

[atomic, fluid dynamics, general, nuclear] Charge cannot be destroyed or altered. Combining a PARTICLE with POSITIVE CHARGE and a particle with NEGATIVE CHARGE as part of the same system will have as a system the net charge for the two particles, as will the combined particle.

Conservation of electromagnetic energy

[energy, general, optics] Based on the MAXWELL EQUATIONS the continuity in ELECTROMAGNETIC RADIATION is defined by $(\partial u_e / \partial t) + \nabla \cdot \vec{S} + \vec{J} \cdot \vec{E} = 0$, where $\vec{E}$ is the ELECTRIC FIELD, $u_e = 1/8\pi(|\vec{E}|^2 + |\vec{B}|^2)$ the ENERGY density per unit volume V , t is time, $\vec{J}$ is the CURRENT DENSITY, $\vec{S} = \sqrt{\epsilon_0 \mu_0} / 4\pi (\vec{E} \times \vec{B})$ the POYNTING VECTOR, $c = \sqrt{\epsilon_0 \mu_0}$ the speed of light, $\vec{B}$ is the MAGNETIC FIELD, $\vec{n}$: the normal to the surface: $\mathcal{A}$, of the enclosed space, and $\vec{J} \cdot \vec{E}$ represents the work per unit time per unit volume performed as a function of the ELECTROMAGNETIC FIELD interaction.

Conservation of energy

[general] The principle that ENERGY can neither be created nor destroyed, and therefore the total amount of energy in the UNIVERSE is constant. This law of classical PHYSICS is modified for certain nuclear reactions (see CONSERVATION OF MASS–ENERGY).

Conservation of linear momentum

[general, mechanics] Specifically applying to lossless collisions (no external net forces, specifically no FRICTION, no *permanent* deformation), the momentum $\vec{p}$ as a vector will be conserved when transferred to a different set of objects, or adding object to the MOTION: $\vec{p} = \sum_n m_i \vec{v}_i$, for a system with constituents with mass m_i , each traveling with respective velocity v_i ; where $\Delta \vec{p} = 0$ (see Figure C.68).



Figure C.68 During the game of pool (billiards) the principle of conservation of momentum is the driving principle however; there are friction losses involved during the rolling action of the billiard balls.

Conservation of mass

[thermodynamics] In principle, MASS (m) cannot be destroyed. The exception will be nuclear reactions where mass can be converted into ENERGY based on ALBERT EINSTEIN's (1879–1955) energy principle: $E = mc^2$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light. In FLOW the conservation principle applies to gasses

and liquids, where the mass is captured by the DENSITY (ρ) multiplied by the VOLUME (V), $m = \rho V$. In chemical reactions the conservation of mass is represented by the reaction equation; no atoms are lost in the forming or dissociation of molecules and residue atoms. The concept of flow is a primary example of the conservation of mass principle (see Figure C.69).



Figure C.69 Conservation of mass illustrated.

Conservation of mass–energy

[general, mechanics] The principle that both mass and ENERGY combined are conserved based on the principle that energy and mass are interchangeable in accordance with the equation: $E = mc^2$, where E is the energy, m is the mass, and c is the velocity of light.

Continuity equation

[fluid dynamics, general, nuclear] The general conservation laws: CONSERVATION OF MASS, conservation of momentum, and CONSERVATION OF ENERGY, as well as CONSERVATION OF ANGULAR MOMENTUM, next to CONSERVATION of charge.

Continuum

[fluid dynamics] For instance a KNUDSEN NUMBER of $Kn \leq 0.1$ sets the boundary conditions where the FLUID FLOW can be treated as a continuous medium, with the MACROSCOPIC parameters such as PRESSURE, TEMPERATURE, VOLUME, VELOCITY, and DENSITY. More confined is the regime $0 < Kn \leq 0.1$, describing diffusive slip-flow in the continuum.

Convectively coupled Kelvin wave (CCKW)

[fluid dynamics, mechanics, meteorology] Atmospheric NONDISPERSIVE WAVE feature, resembling a chimney effect, primarily centered close to, or on the equator that can extend for thousands of kilometers. CCKW consists of a WALL of rising AIR, which tends to tilt to the west with increasing altitude (primarily resulting from the earth's rotation). The rising air is accompanied by air masses that FLOW toward the earth's

surface, generating a CIRCULATION which generates thunderstorms when reaching the air at lower altitude. These RAIN storms are reinforcing the effect combined with DIVERGENCE in air flow at higher altitude leading to cyclonic SPIN. Especially when two of these systems reach each other, for example, a westward rolling pattern across the Atlantic Ocean clashing with an eastward migrating CCKW can provide the mechanism for the generation of tropical cyclones. CCKW is also referred to as the active convective PHASE associated with the Madden–Julian OSCILLATION (named after the scientists and meteorologists from the United States: Roland A. Madden [1938–] and Paul Rowland Julian [1929–]; introduced in 1994). The El Niño—Southern Oscillation is a phenomenon that is related, only under a standing pattern. These waves generally travel with a PHASE VELOCITY of 10–17 m/s, which is a function of the geographic location. The time frame associated with Kelvin waves is exemplified by the fact that it takes approximately 45 days to 2 months for the CCKW to traverse the Pacific Ocean from west to east. However, the anomalies associated with the migration pattern (e.g., tropical storms) may arise as fast as weeks, over a DISTANCE in the order of several hundred kilometers (see Figure C.70).

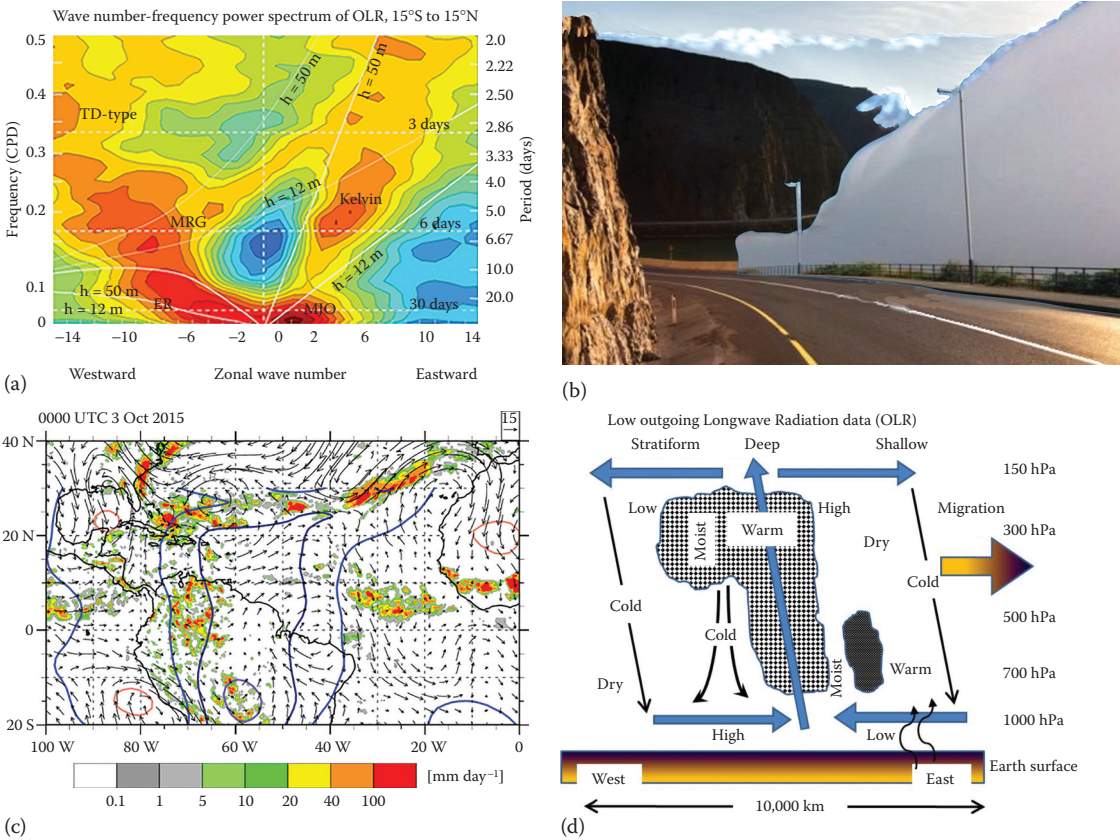


Figure C.70 (a) Schematic cross section through a convectively coupled Kelvin wave (CCKW). (b) Real-life CCKW phenomenon as observed on land in Dubai. (c) CCKW diagram at 40° and 70° latitude outlined by the “Frequency Zonal Wave number; frequency spectrum.” (Courtesy of Michael Ventrice.) (d) OLR, outgoing longwave radiation data. (Courtesy of Paul Roundy.)

Cooper, Leon Neil (1930–)

[condensed matter, electronics, solid-state] Physicist from the United States. Leon Cooper in collaboration with JOHN BARDEEN (1908–1991) and JOHN ROBERT SCHRIEFFER (1931–) developed a theoretical model for SUPERCONDUCTIVITY, referred to as the BCS theory of superconductivity. The Nobel Prize in PHYSICS was awarded to all three men in 1972 for their contributions.

Cooper pair

[condensed matter, electronics, solid-state] Pair of free electrons (conducting electrons) in a crystalline solid that behave as they are linked together by means of a long-range interaction. The Cooper pair provides a credible explanation of certain aspects associated with the phenomenon of SUPERCONDUCTIVITY. The first observation of superconductivity was in 1911 by the Dutch physicist HEIKE KAMERLINGH ONNES (1853–1926). The Cooper pair electrons will migrate through the LATTICE structure totally free of being impeded by the crystalline structure itself, nor any impurities, providing the conditions for zero RESISTANCE.

Copernicus, Nicolaus (1473–1543)

[astronomy, astrophysics, general] (alias of Niklas Koppernigk) German astrophysicist and MEDICINE student. His astrophysics work contributed (although delayed) to the adjustment of the calendar (Gregorian calendar 1581). Copernicus defended the HELIOCENTRIC planetary system (SUN as the center) with detailed scientific observations and theoretical proof in contrast to the accepted GEOCENTRIC system (EARTH as the center) postulated by CLAUDIUS PTOLEMAEUS (also PTOLEMY) (c. 90–168 AD). The Copernican heliocentric model also included the proof of a revolving Earth. Copernicus, however, still assumed the world to be a spherical object, which was challenged by WILLIAM GILBERT (1540–1603) in 1600, favoring an ellipsoidal model (see [Figure C.71](#)).



Figure C.71 Nicolaus Copernicus (1473–1543). (Courtesy of E. Scriven.)

Coriolis, Gaspard-Gustave de (1792–1843)

[fluid dynamics, general, mechanics] Physicist from France. In 1835 Coriolis recognized that the rotational MOTION affects the direction of the path of an object as well as the FLOW of liquids. Additionally, Coriolis introduced the displacement DISTANCE ($\vec{s}$) resulting from an applied force ($\vec{F}$) as work, $W = \vec{F} \cdot \vec{s}$, in 1829 (see [Figure C.72](#)).



Figure C.72 Gaspard-Gustave de Coriolis (1792–1843).

Coriolis effect

[computational, fluid dynamics, mechanics, thermodynamics] The principle that the direction of the path of an object as well as the FLOW of liquids is affected by rotational MOTION, introducing a *motion-dependent* acceleration and resulting redirection, while no apparent real external force is present. The acceleration of moving object under influence of a rotating reference frame was described by GASPARD-GUSTAVE DE CORIOLIS (1792–1843) in 1835. The phenomenon is however still also referred to as CORIOLIS FORCE. The Coriolis effect will for instance result in a higher water level on the east side of a river running south to NORTH on the northern hemisphere and on the western riverbank for a similar river on the southern hemisphere. The river itself on the northern hemisphere will also tend to starboard. The same will apply to a sail boat, but these effects are so small that they will be negligible, and may never be recognized due to other external forces, such as wind force. Alternatively, because of Coriolis effect the AIR flow on the northern hemisphere will be forced to move in counterclockwise direction, which is clearly visible when observing hurricanes (“Atlantic Ocean”) and typhoons (cyclonic action in the northwest Pacific basin: western North Pacific ocean; between the 180° longitude and the 100° east longitude) as observed from a weather SATELLITE position (see [Figure C.73](#)).

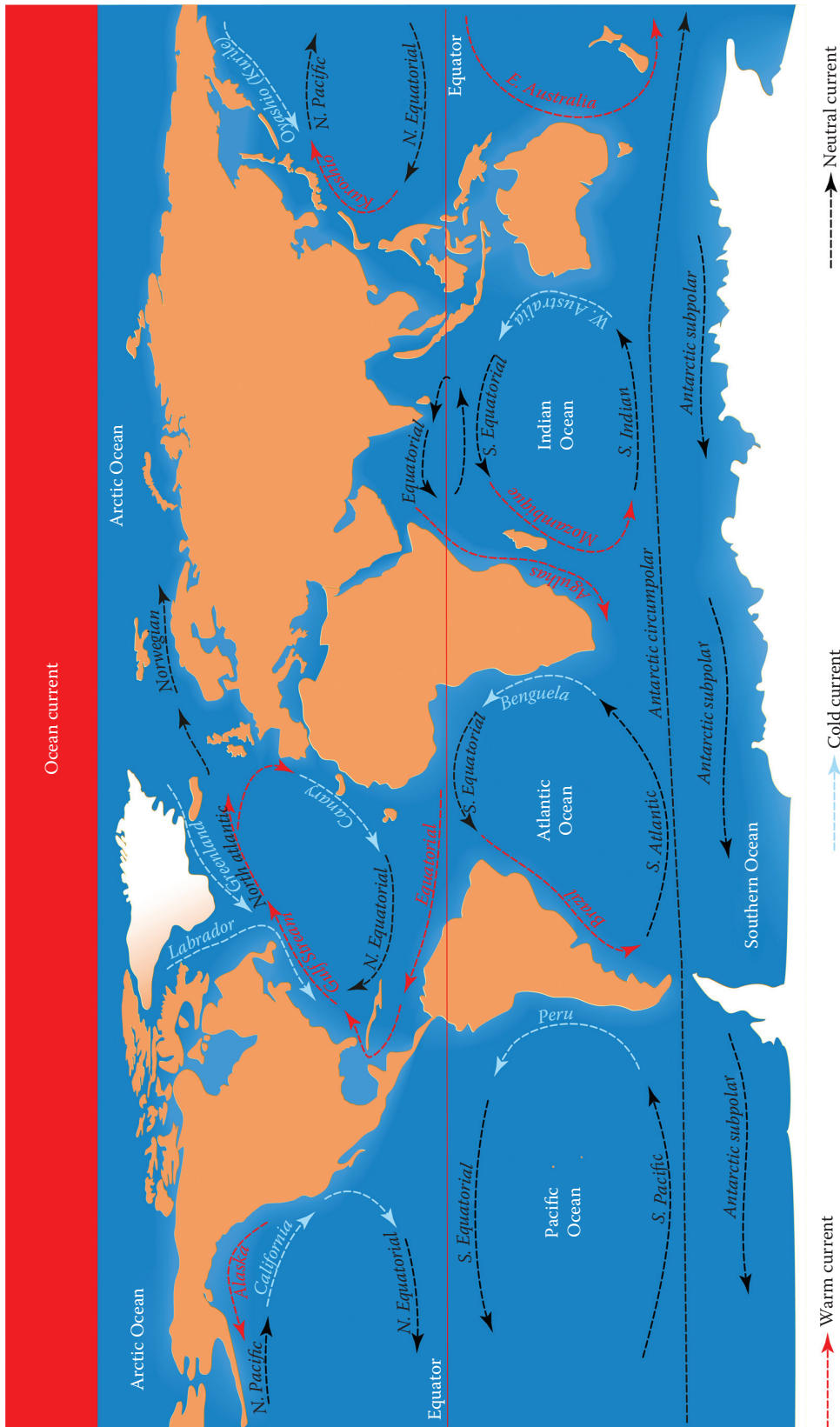


Figure C.73 The influence of the earth's rotation on the ocean currents under the Coriolis effect.

Coriolis force

[computational, fluid dynamics, mechanics, thermodynamics] Force exerted on an object with mass m by its movement with VELOCITY $\vec{v}$ with respect to a rotating system with ANGULAR VELOCITY ω expressed as $F = m * -2\vec{\omega} \times \vec{v}$, specifically identified by the acceleration aspect, $\vec{a} = -2\vec{\omega} \times \vec{v}$. The fictional force is primarily perpendicular to the MOTION of the object. This results, for instance, in having the water level on one side of a flowing river to be higher than the opposite side with respect to sea level due to the earth's rotation.

Coriolis frequency (ν_{coriolis})

[computational, fluid dynamics, mechanics, thermodynamics] The vertical component of the angular VELOCITY (ω), also referred to as the PLANETARY VORTICITY, defined as $\nu_{\text{coriolis}} = 2\omega \sin \theta$, where θ is the reciprocal ANGLE with respect to the normal to the earth's surface, that is, the LATITUDE on the globe (see Figure C.74).

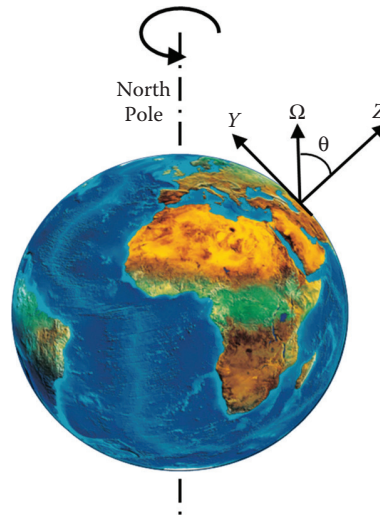


Figure C.74 The Coriolis frequency concept.

Corona (-discharge)

[electromagnetism, general] Electric FLUX of excess charges from a surface under the influence of a POTENTIAL DIFFERENCE V between two locations separated by a DISTANCE d . The potential difference may result from a variety of factors, man-made or natural. The potential difference thus generates an ELECTRIC FIELD E that is partially influenced by the radius of curvature (r_c) of the object with the excess charge (*also see ELECTRIC FIELD IN CONDUCTOR* as function of radius of curvature of the surface contour). When the radius is much smaller than the separation distance between the opposite charged points the conditions for a corona discharged arc are greater with exceeding ratio. The electric field resulting from the excess electron ionizes the gas(es) that fill the space between the charged points. The electric field and the discharge of charges creates a PLASMA in the GAS between the locations with opposite charge. One specific example is the glowing discharge in a neon light. Another example is lighting, which creates a PLASMA of the oxygen (O_2) in atmospheric AIR, forming ozone (O_3). Coronas are also used in copying MACHINES to charge nonconducting surfaces to hold ink for transfer of an IMAGE. Free ELECTRONS are drawn into the electric field in the CONDUCTOR, with a field distribution that depends on the radius of curvature, smaller radius higher field due to the higher surface charge density. The electrons (e) with electron charge are accelerated (a) by the electric field due to the ELECTRIC FORCE, $F = eE = ma$. The accelerated electrons collide with the resident neutral molecules at a high frequency of $\nu_{\text{en}} \sim 10^{12}$ Hz. At this point the ENERGY of the electrons is still limited by the INELASTIC COLLISIONS and remains below the PHOTOELECTRIC EFFECT energy. Only a limited number of electrons will escape from the surface of the conductor, contributing to the discharge arc. In standard air pressure with relative HUMIDITY 60%, a corona will form for a rounded surface

with radius $200\text{ }\mu\text{m}$ under 5 kV electrical potential when placed at a distance of 10^{-2} m with a conductive plate. This discharge voltage increases to 10 kV when the diameter is 2 mm (*also see ARC, LIGHTNING, SPARK, and ST. ELMO'S FIRE*) (see [Figure C.75](#)).



Figure C.75 Corona discharge.

Cortical bone

[biomedical] Dense bone of the human skeleton, making up approximately 80% of the bone structure. The cortical bone is strong and can support large shear force. The remaining bone structure is CANCELLOUS BONE. The main function of the cortical bone is to support and transfer force (e.g., femur, humerus, tibia, more generally [but not limited to] the bones in the arms and legs). Cortical bone forms the protective hard shell of all bone materials. The core material of skeletal bone still often consists of cancellous osseous tissue bones. It is also referred to as compact bone (see [Figure C.76](#)).

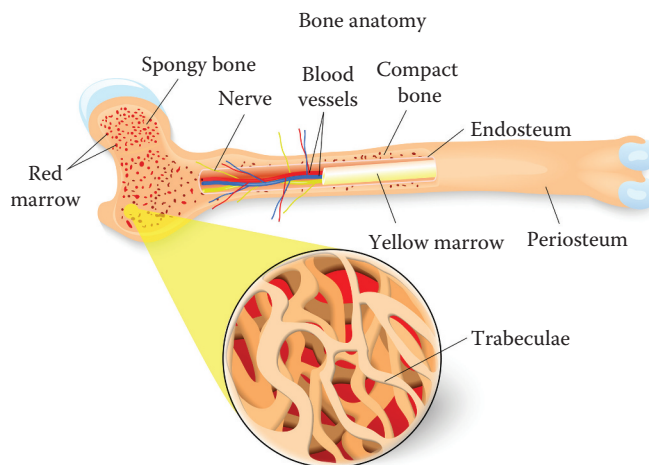


Figure C.76 Cortical (compact) bone layer of skeletal bone structure.

Cosmic force

[general] Set of laws applying to planetary and SATELLITE MOTION and gravitational interaction on galactic scale derived from the work by TYCHO BRAHE (1546–1601) and his successor JOHANNES KEPLER (1571–1630). The general concept of cosmic force is captured by the Kepler's THREE LAWS OF PLANETARY MOTION, next to the

description of satellite ORBITS (applying to comets and ASTEROIDS), and additionally, the description of the GRAVITATIONAL FIELD, including the hypothetical gravitational PARTICLE the “GRAVITON.”

Cosmic rays

[astronomy/astrophysics, atomic] RADIATION consisting of both ELECTROMAGNETIC ENERGY as well as particles emerging from outer space as well as from the SUN. Cosmic rays consist of gamma rays, protons, ALPHA PARTICLES, neutrinos, and electrons next to a minor contribution from isotopes of heavy nuclei. The interaction of cosmic rays with atoms in the upper ATMOSPHERE of EARTH generate excitation and DECAY effects next to SCATTERING, which all result in (cascade of; depending on the incident energy) secondary radiation. The stream of PARTICLES and ELECTROMAGNETIC RADIATION reaching Earth from the SUN, the stars in our MILKY WAY as well as emission from other galaxies. The particles range in ENERGY from 10^6 eV to in excess of 10^{22} eV and are composed of PROTONS (~86%), HELIUM NUCLEI (alpha particles; 12.7%), heavy NUCLEI (1.3%) as well as ELECTRONS (~1%) and a TRACE of electromagnetic radiation (depending on the interpretation). At the lower end of the scale, GAMMA RAYS released in the production of π^0 eV MESONS have an energy of approximately 10^5 eV, higher energies are in electrons and positrons, increasing to ALPHA PARTICLES (He^{2+}). Additionally, NEUTRINOS and a mixture of nuclei are also detected using methods including BUBBLE-CHAMBER. At the highest range the energetic content is dominated by protons at increasing VELOCITY. The particle FLUX (“ j ”) for PARTICLE in excess of a specific threshold energy (E) is expressed as $j(> E) = K_{\text{cosmic}} E^{-\delta}$, where K_{cosmic} and δ are positive constants in the energy regime described by the POWER LAW $E \geq 10 \text{ GeV/nucleon}$.

Cosmic string

[astrophysics, computational, nuclear, quantum, theoretical] In the relativistic QUANTUM theoretical description of symmetry breakdown there are hypothetical defects or DISCONTINUITIES in linear dimension that are referred to as cosmic strings. The theoretical concept is bound by ENERGY in excess of ~ TeV in very short dimensional PHYSICS. The cosmic string is part of STRING THEORY, in this case relating energy configurations of oscillating open string networks that extend to infinity as well as vibrating closed loops. The general concept of string theory is captured in SCHRIEFER UNIFIED THEORY.

Cosmonaut

[astronomy/astrophysics, general] Astronaut under the Union of Soviet Socialist Republics (USSR; now Russian Federation, “Russia”) space flight program (see [Figure C.77](#)).



Figure C.77 Russian cosmonaut Yuri Gagarin.

Couette flow

[fluid dynamics] Laminar FLUID FLOW between plates with a gradual, and frequently linear, gradient in flow velocity. Couette flow obeys the simplified Navier–Stokes equation, $d^2u/dy^2 = 0$, where u represent the flow velocity parallel to the planes in the “X-direction” and y is the plate separation DISTANCE: the plates can move with respect to each other, the plates can be curved for the case of concentric cylinders, and the flow can describe the fluid MOTION between stationary plates. The flow velocity as a function of distance between two plates at separation h for a fluid with VISCOSITY η with respect to a PRESSURE (P) gradient in the direction of flow x can be described under two conditions: (1) moving plate or (2) stationary plates. The moving (sliding) plates SOLUTION for relative velocity u_0 yields $u(y) = u_0(y/h) + (1/2\eta)(dP/dx)(y^2 - hy)$. The laminar Couette flow, with average flow velocity $u_{\text{avg}} = -(h^2/8\eta)(dP/dx)$ between stationary plates is described with respect to the center plane at $h/2$ in the form $u = 3/2u_{\text{avg}}[1 - (4y^2/h^2)]$, which has similarity to POISEUILLE FLOW and will develop into Poiseuille flow for larger flow velocity. Additional combination solutions are available, with a special case of plates moving in opposite direction. Couette flow generally describes shear stress-dependent flow, such as found in the connection between the piston rod and the crankshaft for an automobile ENGINE, however only below a critical REYNOLDS NUMBER. The flow velocity between two rotating concentric cylinders, with R_1 the inner cylinder radius, R_2 the outer cylinder radius, and ω the relative ANGULAR VELOCITY, as a function of radius (r) is $u_\theta(r) = (\omega R_1^2/r)[(R_2^2 - r^2)/(R_2^2 - R_1^2)]$. In Poiseuille flow, the flow velocity has a quadratic dependence to the location on the radius of the tube under an applied pressure gradient along the length of the tube. Similarly, in Couette flow the flow between two stationary plates has a quadratic dependence to the midpoint plane between the two plates. In comparison, the Poiseuille flow MAGNITUDE in a tube will have a dependency to the tube radius to the fourth power where Couette flow will only yield a maximum of quadratic dependence on plate separation. This type of flow is primarily found under low flow velocity, or alternatively low translational velocity of two plates with respect to each other, separated by a viscous fluid. Couette flow is not stratified and has constant vorticity. Under conditions of spanwise rotation, a plane turbulent Couette flow can develop where the velocity is SPIN in forward and backward flow with respect to the central line between the two moving object, again with only gradual gradient in flow velocity as a function of separation distance, and zero flow velocity on the central dividing plane (see Figure C.78).

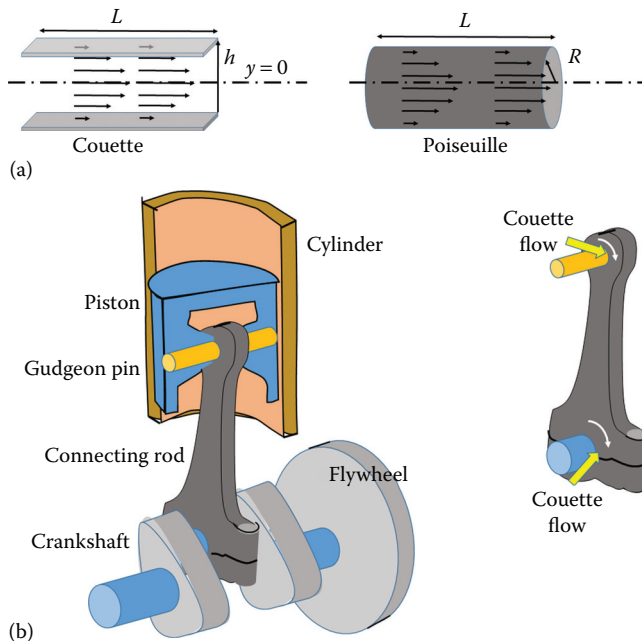


Figure C.78 Couette flow: (a) comparison between Couette and Poiseuille flow and (b) example of locations for potential Couette flow.

Coulomb, Charles-Augustin de (1736–1806)

[energy, general] French scientist whose publication of electric attraction in 1785 (*Histoire et Mémoires de l'Académie Royal des Sciences*) “Coulomb’s Law” opened the doors for the BOHR ATOMIC MODEL as well as (see [Figure C.79](#)).



Figure C.79 Charles-Augustin de Coulomb (1736–1806).

Coulomb, unit

[chemical, electronics] ELECTRIC CHARGE unit, defined indirectly from the Lorentz force between two parallel wires conducting a current of 1 ampere, where $1\text{ A} = 1\text{ C/s}$ defines the FLOW of an electric charge of 1 coulomb across the cross-sectional area of the wire per SECOND.

Coulomb apparatus

[general] TORSION balance used by CHARLES-AUGUSTIN DE COULOMB (1736–1806) to derive the ELECTROSTATIC FORCE between ELECTRIC CHARGES. A gold leaf-covered ball attached to a rod is suspended from a silver wire, counterbalanced by a loop with a paper disk. The suspended ball will be charged by a rod that has an electric charge applied, for instance, a GLASS rod that has been rubbed by silk. The suspended rod is in the same horizontal plane with a ball of identical material and size as the suspended ball is fixed in three-dimensional space by a nonconducting geometric device. When the two balls are in contact, and if the balls are touched by a charged rod, both will be loaded with the same electrostatic charge (both in sign and MAGNITUDE) and will REPEL. The balls will move away from each other to the point where the TORQUE and electrostatic force are balanced, based on NEWTON’S THIRD LAW, and the charge can be derived. Based on COULOMB’S LAW the electrostatic force will be equal to the force applied to the arm of the suspended rod, expressed as torque.

Coulomb potential

[atomic, condensed matter, energy] $V^{\text{Coulomb}} = e^2/r$, where $e = -1.6 \times 10^{-19}\text{ C}$ is the electron charge, however, this also applies to protons as a POSITIVE CHARGE, and r the separation between the protons.

Coulomb's law, electrostatic charge

[chemical, electronics, mechanics] The force of attraction or repulsion (F_e) exerted between two electrostatic charges, Q_1 and Q_2 , respectively, with a DISTANCE, s , separated by a medium of DIELECTRIC value, ϵ , is given by the equation $F_e = (1/4\pi\epsilon)(Q_1Q_2/s^2)$. Introduced by CHARLES-AUGUSTINE DE COULOMB (1736–1806).

CPT theorem

[computational, thermodynamics] Charge–space–time theorem. Invariance of the LAGRANGIAN THEORY under standard “proper” LORENTZ TRANSFORMATION, specifically pertaining to QUANTUM FIELD THEORY. Additionally the Lagrangian theory is invariant to TIME reversal (in either direction) (T), CHARGE conjugation (C), and SPACE INVERSION (P). In CHARGE CONJUGATION, all particles are transformed into their respective antiparticles. The independence to the space-time CONTINUUM requires the following condition to maintain invariance, $\Lambda_{\zeta\mathcal{G}}\Lambda_{\zeta\mathcal{G}} = \delta_{\mathcal{G}\mathcal{G}}$, yielding a KRONECKER DELTA FUNCTION for the MATRIX multiplication.

Crab Nebula, pulsar

[general] Remnants of a SUPERNOVA that presumably exploded in 1054 AD, based on documented observations by Chinese astronomers (keeping in mind the rudimentary tools available at the time and the DISTANCE). The Crab Nebula is at approximately 2000 parsecs from EARTH (1 parsec = 3.26 light-years = 3.1×10^{16} m). According to the documentation, the explosion was visible for two years, three weeks of this was also during the daytime. At the center of the nebula is a pulsating NEUTRON STAR, spinning in similar fashion to an old-fashioned lighthouse beam, with steady pulsating frequency of 30 Hz. The estimated size of this pulsating neutron star is merely 25 km, but has the mass of our SUN (see Figure C.80).

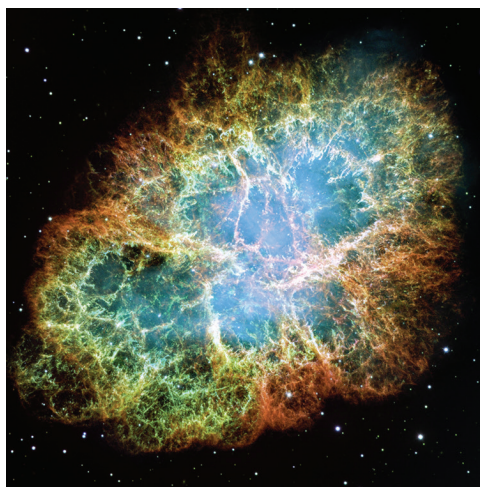


Figure C.80 Crab Nebula, part of the constellation Taurus. Remnant of a supernova that supposedly exploded in 1054 AD. The Crab Nebula has a strong pulsar neutron star in its core. (Courtesy of NASA/STScI, Space Telescope Science Institute, Baltimore, MD.)

Creep

[general, mechanics] Anelastic deformation of a solid medium. Anelastic creep is defined by a nonlinear elastic behavior described as a function of stress ($\sigma_{\text{stress}} = F/A$, the force F acting parallel to the area A) and strain ($\epsilon_{\text{strain}} = \Delta L/L_0$; L the length): $J_R\sigma + \tau J_{\mathcal{H}}(\partial\sigma/\partial t) = \epsilon + \tau(\partial\epsilon/\partial t)$, where J_R , $J_{\mathcal{H}}$, and τ are material constants and τ the RELAXATION TIME with respect to deformation. The material can be defined by a complex COMPLIANCE, $J^* = \epsilon_{\text{strain}}/\sigma_{\text{stress}} = J_1 + iJ_2$, where the real part of the compliance (J_1) is in PHASE with the applied stress. For a cyclically (ANGULAR FREQUENCY ω) applied stress the compliance is related to the constants as $J_1(\omega) = J_{\mathcal{H}} + [(J_R - J_{\mathcal{H}})/(1 + \omega^2\tau^2)]$ and $J_2(\omega) = (J_R - J_{\mathcal{H}})\omega\tau/(1 + \omega^2\tau^2)$ (known as

the DEBYE EQUATIONS). The relaxation process under elastic deformation adheres to $\tau = \tau_0 e^{E_A/k_B T}$, as a function of the activation ENERGY required for the process and the temperature T (Boltzmann coefficient: $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$). Applying specific boundary conditions this will provide three specific types of creep: anelastic, secondary, and tertiary creeps. For instance, anelastic creep can be assumed under constant stress, which provides $\epsilon_{\text{strain}}(t)/\sigma_{\text{stress},0} = J_{\infty} + (J_R - J_{\infty})[1 - e^{-(t/\tau)}]$. This process also applies to phonon propagation and “dislocated” LATTICE vibrations (vibrational damage). In biomedical context, this can relate to HEARING losses resulting from excessively loud music for extensive periods of time (see [Figure C.81](#)).

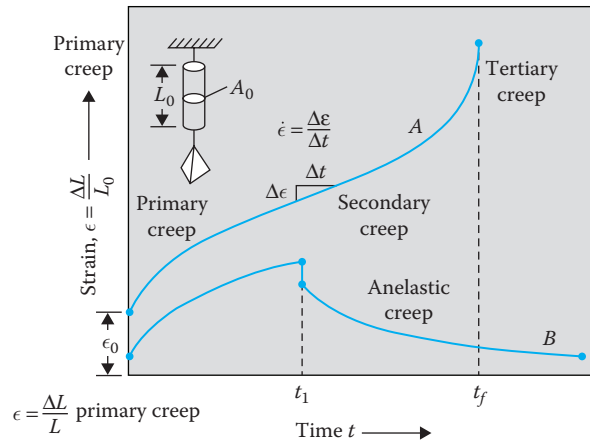


Figure C.81 The creep phenomenon.

Crick, Francis Harry Compton (1916–2004)

[biophysics, general] Molecular biologist, neuroscientist, and biophysicist from England, codiscoverer of the double helix structure of DNA with JAMES DEWEY WATSON (1928–), published in 1953. He dedicated his work to unraveling the mystery of the genetic code, and published the DNA–RNA–protein correlation as a one-way FLOW of genetic information (see [Figure C.82](#)).

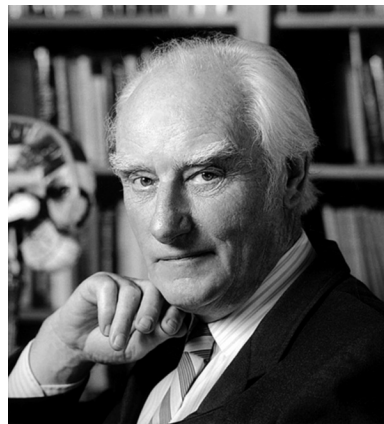


Figure C.82 Francis Harry Compton Crick (1916–2004).

Critical angle (θ_c)

[general] ANGLE of incidence at an interface between two media of different index of REFRACTION at which total REFLECTION occurs. The critical angle is based on the refracted angle of 90° under SNELL'S LAW. The critical angle is of particular importance in FIBER-OPTIC transmission (see [Figure C.83](#)).

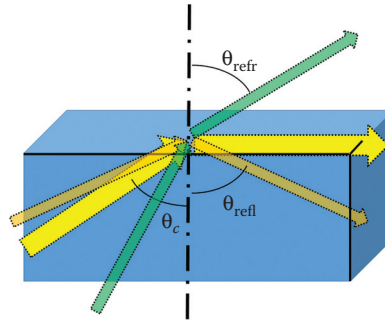


Figure C.83 Critical angle for refraction/reflection.

Critical point (c , subscript: "c")

[general, thermodynamics] The boiling point of liquids is directly correlated to the pressure. An increase in pressure will result in a proportional increase in boiling temperature. The difference in density between VAPOR and FLUID phase diminishes with increasing pressure and temperature until the critical point is reached and the density of the LIQUID and vapor phases become equal. This phenomenon is a SECOND-ORDER PHASE TRANSITION. Examples of media operating at the critical point are superconductors, ferro-magnets experiencing spontaneous magnetization, ferroelectrics exhibiting POLARIZATION, and binary fluids, which will separate out the two phases of the constituents (see CRITICAL TEMPERATURE [T_c] and CRITICAL PRESSURE [P_c]) (see [Figure C.84](#)).

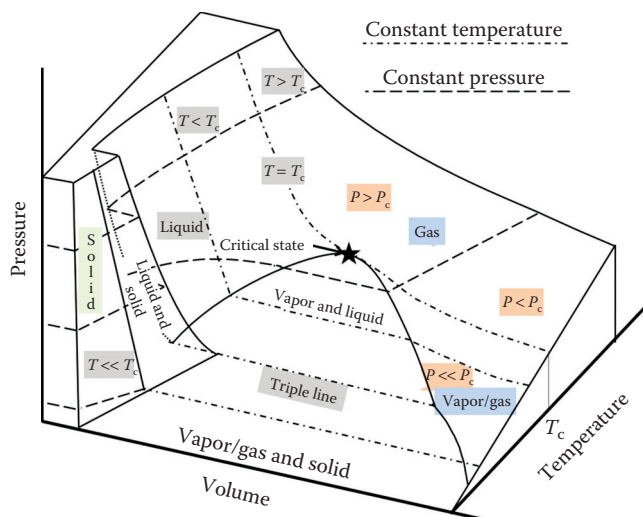


Figure C.84 Dependence of the conductivity of a medium with respect to the critical temperature.

Critical size

[nuclear] The minimum amount of a fissionable material that will support a CHAIN REACTION.

Critical temperature (T_c)

[general, thermodynamics] Temperature below which a material relinquishes its RESISTANCE and becomes superconductive (see [Figure C.85](#)).

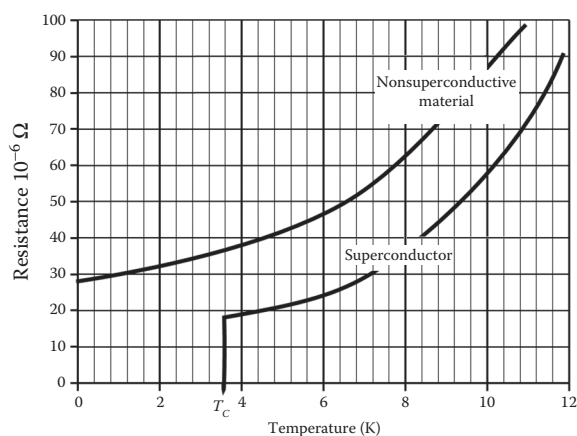


Figure C.85 Critical point in a phase diagram for a substance that contracts when melting, for instance, water. In contrast, carbon dioxide is a substance that will expand upon melting.

Crookes, William, Sir (1832–1919)

[atomic, electronics, nuclear] Physicist from Great Britain who introduced the investigational ELECTRODE tube, the CROOKES TUBE in 1870 (see [Figure C.86](#)).



Figure C.86 Sir William Crookes (1832–1919). (Courtesy of Leslie Ward, *Vanity Fair*, 1903.)

Crookes tube

[atomic, electronics, nuclear] VACUUM CRT introduced by SIR WILLIAM CROOKES (1832–1919), predecessor to the modern neon light signs. The Crookes tube was based on the earlier observations in a vacuum BAROMETER by the French physicist JEAN PICARD (1620–1682) (see [Figure C.87](#)).

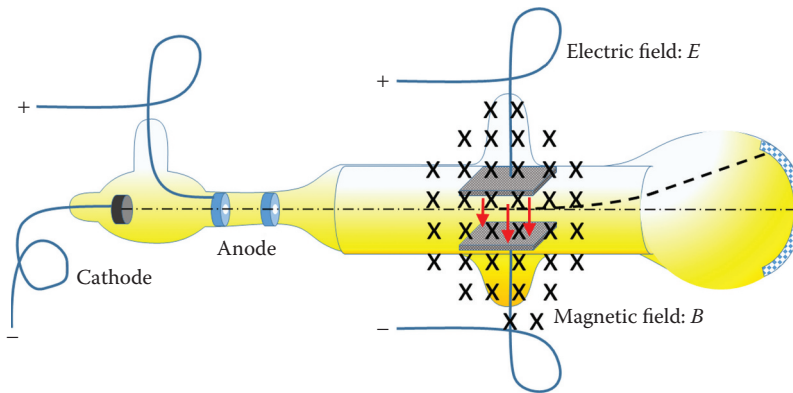


Figure C.87 Crookes tube and mechanism of operation.

Cross section

[atomic, general, mechanics, nuclear] The area subtended by an ATOM or molecule for the PROBABILITY of a reaction, that is, the reaction probability measured in units of area.

Cryodesiccation

[biomedical, energy, general] Freeze-drying, *also see* LYOPHILIZATION. Preservation mechanism for biological media used to slow down the chemical processes as well as facilitate the removal of water by means of deep-freeze quick cold storage.

Cryogenics

[atomic, biomedical, electronics, general, nuclear] Mechanism of producing extremely low temperature to observe the changes in physical properties of a material. The most known applications in cryogenics are in superconductivity. Most cryogenic processes take place at temperatures below 123K $\sim$ -150°C . In biomedical applications the temperature requirements are not that extreme, for instance, the preservation of sperm for in vitro fertilization. In biological applications, generally, the use of frozen carbon dioxide (also known as “dry-ice”) provide the mechanism for quick reduction of temperature by submersion. The MELTING POINT of the solid CO_2 is $\sim -79^{\circ}\text{C}$. Attempts of cryogenics on large objects is primarily limited by the heat DIFFUSION and heat capacity of the object in question. FREEZING entire human bodies, for instance, will require PERFUSION with LIQUID CO_2 , otherwise the core will remain too warm for too long a period and there will be risk for cracking of the solid outer shell due to the fact that most materials either expand or reduce in size with decreasing temperature. At lower temperatures, the molecular mobility will reduce (*see* TEMPERATURE) resulting in a reduction of the PROBABILITY for collision of migrating free electrons under the influence of an applied external electric field, that is, SUPERCONDUCTIVITY.

Crystalline lens

[biomedical, general, optics] ADAPTIVE OPTICS instrument in the HUMAN EYE that can be adjusted for FOCAL LENGTH by contraction and relaxation of the MUSCLE in the EYE attached to the LENS. When the muscles are relaxed the lens is most rounded with the IMAGE of the “NEAR POINT” focused on the RETINA at approximately 24 mm from the lens. On contraction the lens flattens out, increasing the focal length, as defined by the LENS EQUATION, to the point of focusing “infinity” on the retina. The near point is at approximately 25 cm DISTANCE from the eye for the average adult, whereas children have a shorter near point (see ACCOMMODATION) (see [Figure C.88](#)).

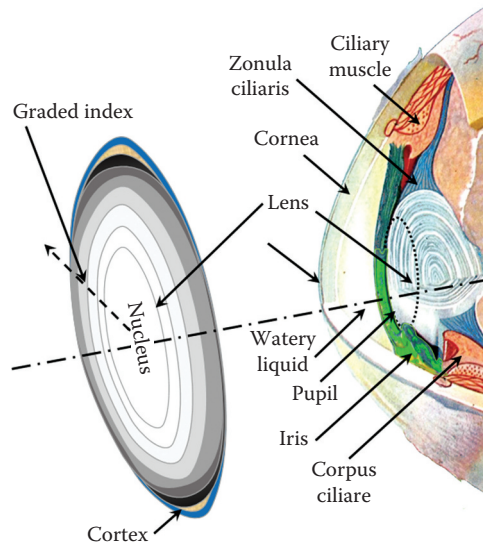


Figure C.88 Crystalline lens of the human eye forming an image on the retina for signal acquisition and processing by the brain.

Cubic amplifier

[computational, electromagnetism, general, theoretical] Nonlinearity in electric amplifier. Amplifier with a gain performance profile that can mathematically be described by a polynomial up to the third order (i.e., cubic) without significant loss in accuracy. The polynomial terms can incorporate the higher harmonics and desensitization of INTERFERENCE (i.e., band-block filter or “jammer”) (also see VAN DER POL EQUATION).

Curie, Manya (Marie) Skłodowska (1867–1934)

[atomic, general, nuclear] Scientist and physicist, who left her homeland of Poland to start her doctoral studies at the French Sorbonne. Because of the exposure to RADIATION Marie Curie eventually died of cancer (see [Figure C.89](#)).

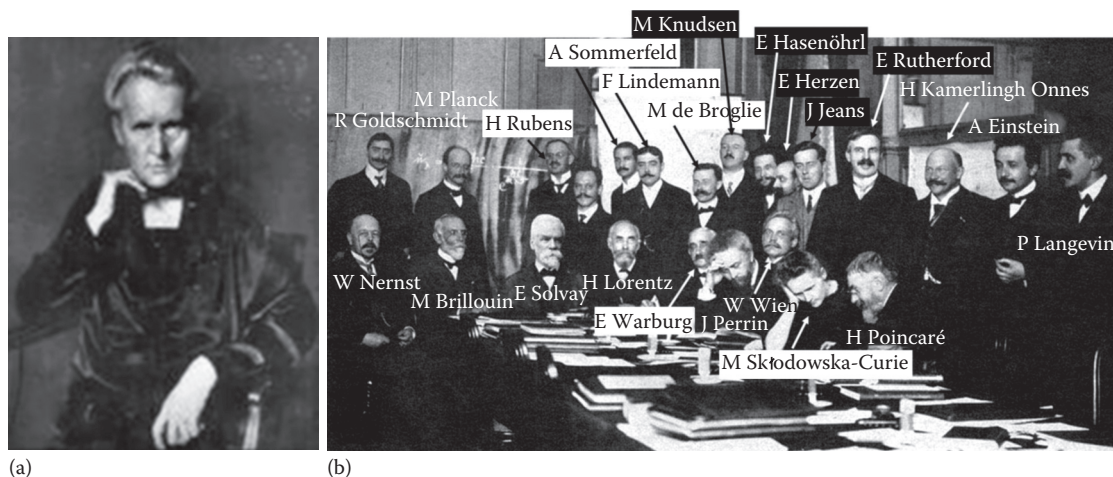


Figure C.89 (a) Manya (Marie) Skłodowska Curie (1867–1934) at the 1911 Solvay conference: “Conseil Solvay,” organized by the industrialist Ernest Solvay by invitation only. Ernest Gaston Joseph Solvay (1838–1922) chemist from Belgium, shown in (b). The conference was held in Brussels in the latter part of 1911. The subject of the conference was a very popular topic of the day: “Radiation and the Quanta.” The conference became open to the general scientific audience in 1912, upon peer review.

Curie, Paul-Jacques (1856–1941)

[atomic, general, nuclear] Scientist from France responsible for the discovery of the piezoelectric ACTIVITY of crystalline structures under deformation in 1880. Some of the crystalline structures under investigation were QUARTZ, tourmaline, and Rochelle SALT. Brother of PIERRE CURIE (1859–1906) (see [Figure C.90](#)).

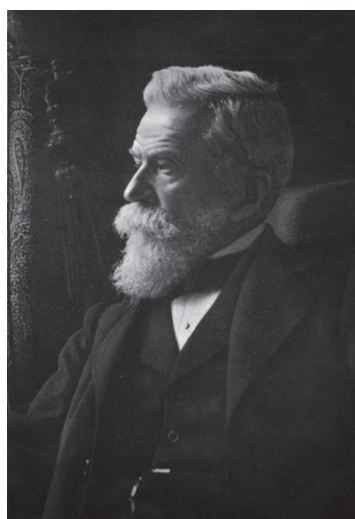


Figure C.90 Paul-Jacques Curie (1856–1941).

Curie, Pierre (1859–1906)

[atomic, general, nuclear] Scientist from France mostly known for his work on RADIOACTIVITY with his wife MARIE CURIE (1867–1934). Exemplary contributions of Pierre Curie are the discovery of radium and polonium, next to his work on his work on crystals and MAGNETISM, specifically the formal description of piezoelectric behavior. The husband–wife research couple shared a Nobel Prize in PHYSICS with ANTOINE HENRI BECQUEREL (1852–1908) in 1903 for their work on RADIATION (see [Figure C.91](#)).

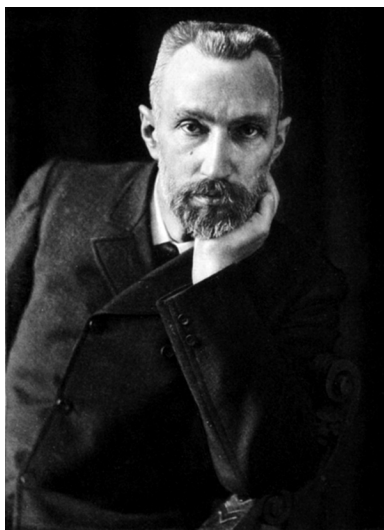


Figure C.91 Pierre Curie (1859–1906).

Curie, unit (Cu)

[atomic, nuclear] Unit of radioactive disintegrations, $1 \text{ Cu} = 3.70 \times 10^{10}$ disintegrations/s. The number of disintegrations closely resembles the radium emittance of ALPHA PARTICLES per SECOND from 1 g; however, the Curie is independent of the PARTICLE disintegration and particular particles emitted. The value of 1 Cu indicates a very powerful RADIOISOTOPE: $7.4 \times 10^4 [(\beta - \text{particle/s})] = 2 \mu\text{Cu}$.

Curie law

[atomic, general, nuclear] Behavior of paramagnetic devices/materials described by PIERRE CURIE (1859–1906). The Curie law relates the MAGNETIC DIPOLE MOMENT (M_B) to the applied MAGNETIC FIELD B as $M_B = C_c (B/T)$, where C_c is the material constant and T the ABSOLUTE TEMPERATURE (in Kelvin). The inverse proportionality with respect to temperature ties in with thermal agitation disrupting alignment.

Curie temperature

[atomic, general, nuclear] The temperature at which the magnetic structures (also called domains) in a PERMANENT MAGNET are disrupted by the kinetic MOTION and the magnet relinquishes its magnetic identity. This phenomenon was discovered by PIERRE CURIE (1859–1906) in 1894. The Curie temperature is material specific, for instance, for magnetite it is 575°C and for hematite 675°C , respectively.

Curium ($^{247}_{96}\text{Cm}$)

[atomic, nuclear] RADIOACTIVE ISOTOPE in the actinide series. The ELEMENT is named after Curie husband and wife research team: MARIE (MANYA) SKŁODOWSKA CURIE (1867–1934) and PIERRE CURIE (1859–1906).

Curl ($\nabla \times \vec{V}$)

[computational] The mathematical vector operator describing “rotation” of a vector or function ($\vec{V}$) within an area ($\mathcal{A}$) at a location ($\vec{r}$); defining the rotation of the vector in infinitesimal steps, hence describing the projection of the vector upon all possible lines passing through the location in the three-dimensional space. The curl is expressed as $\nabla \times \vec{V} \cdot \vec{n} = \lim_{\mathcal{A} \rightarrow 0} (1/|\mathcal{A}| \oint_C \vec{V} \cdot d\vec{r})$, observed as the closed integral over a loop (C), with direction defined by unit direction vector $\vec{n}$ which is the axis of vector rotation. It is also referred as cross-product. A vector field with curl = 0 is considered “irrotational.”

Curl-free vector field

[computational, fluid dynamics] A fundamental component of HELMHOLTZ DECOMPOSITION in vector calculus. In three-dimensional space, the vector field composed of sufficiently smooth, rapidly decaying vectors can be decomposed into the sum of two “orthogonal” components, one consisting of an IRROTATIONAL (CURL-FREE) VECTOR FIELD and the second segment composed of rotational (divergence-free) or solenoidal vector field ($\vec{V}$). The formulation of this series is defined as a function of location ($\vec{r}$) within a volume in space (V) as $\mathbb{C} = (1/4\pi) \int_V \nabla' \cdot \vec{V}(\vec{r}') / |\vec{r} - \vec{r}'| dV' - (1/4\pi) \int_S \vec{V}(\vec{r}') \cdot d\vec{S}' / |\vec{r} - \vec{r}'|$, the second term will have limit zero when the phenomenon comprises all of free space with the vector field rapidly decreasing.

Current (I)

[electromagnetism, general] Electron flow; more specifically the FLOW of “holes,” since the current direction is in the opposite direction of the displacement of electrons. The current flow was based on the assumption that positive PARTICLE were involved, before the analysis of the atomic structure was performed or understood. The flow of electrons relies on a gradient in applied electrical potential (voltage) with an inherent electric field gradient.

Cyclone

[fluid dynamics, geophysics, meteorology] Low-pressure system, generating a FLUID volume rotating in the same direction as the EARTH. The pressure gradients associated with the cyclonic action generates winds that FLOW counterclockwise on the northern hemisphere and clockwise on the southern hemisphere. A meteorological cyclone is generally associated with thunderstorms and heavy rainfall (see [Figure C.92](#)).



Figure C.92 Image from satellite showing cyclone off the Florida coast.

Cyclotron

[atomic, nuclear] PARTICLE ACCELERATOR. Charged particles are released from the center of a circular accelerator and gain velocity with increasing radius (spiral path) as a result of an applied MAGNETIC FIELD. The cyclotron is used to investigate the structure of atomic nuclei and create new ELEMENTS. The cyclotron was invented by ERNEST ORLANDO LAWRENCE (1901–1958) in the 1920s, and was not feasible for practical use until a large enough magnetic field could be generated in the 1930s. Cyclotrons range in size from less than a meter to several meters. The largest cyclotron is the RIKEN in Japan, with a diameter of 19 m, 8 m high, and can operate with a maximum magnetic field strength of 3.8 T. The RIKEN cyclotron can reach 345 MeV of acceleration ENERGY per atomic mass unit. The cyclotron designed by Ernest Lawrence was built in 1939 has a diameter of 1.52 m. A block-wave periodic magnetic field is applied that matches the RESONANCE conditions to induce acceleration, based on the orbital period of the charge. The cyclotron frequency (angular velocity $\omega_{\text{cyclotron}}$; frequency $\nu_{\text{cyclotron}} = \omega_{\text{cyclotron}}/2\pi$) is a function of the applied MAGNETIC field (B) and the MAGNITUDE of the CHARGE (q) on the MASS (m) as $\omega_{\text{cyclotron}} = qB/m$ (see Figure C.93).

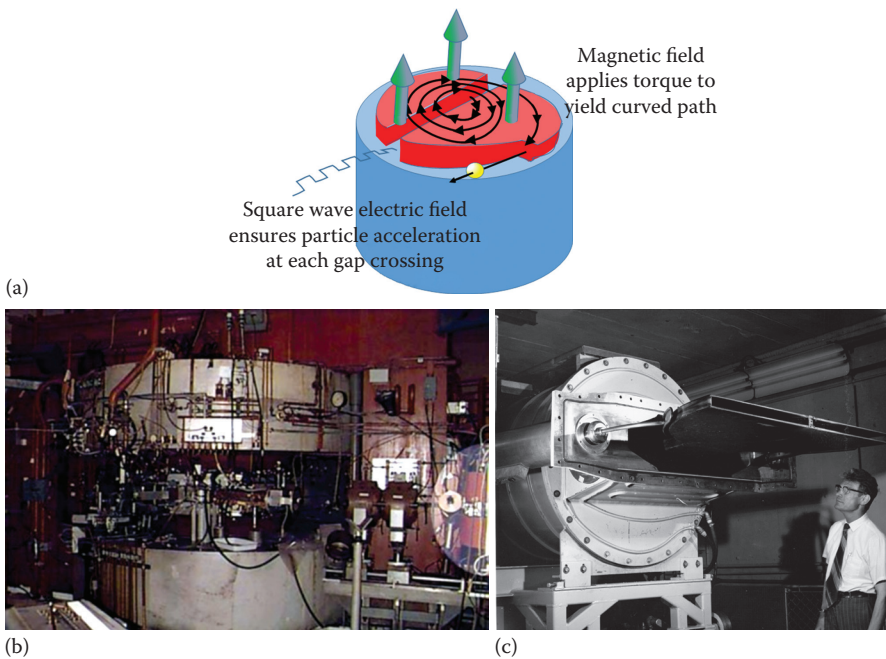


Figure C.93 Cyclotron: (a) mechanism of action for particle acceleration, (b) 1.52 m loop at Argonne National Lab, and (c) David Lind at 26 MeV cyclotron beam guide during the 1962 construction. (Courtesy of University of Colorado, Boulder, CO.)

Da Vinci, Leonardo; Leonardo di ser Piero da Vinci (1452–1519)

[biomedical, computational, fluid dynamics, general, mechanics] A scientist and “renaissance man” from Italy. Leonardo made a significant number of inventions and elaborate ENGINEERING drawings of devices not realized for many centuries (e.g., helicopter, submarine, and SCUBA GEAR). He was an initial proponent for the old VISION theory of EXTRAMISION (approx. 1480), objects radiate out, but later changed his views after anatomical examination of the EYE and became a staunch supporter of the “refection” mode of observation. Additional anatomical observations made him conclude that the skeleton is an elaborate system of levers, powered by MUSCLE, hence introducing the concept of torque. Leonardo also made several devices and instruments for automation of certain tasks. He formed a rudimentary theoretical description of the movements of TECTONIC PLATES. He concluded that the surface on which an object is placed pushes back with the same force as what is resting on it (the weight). He also realized that FRICTION was proportional to the “weight” of an object, the normal force, but different depending on surface treatment or choice of materials. He also drew a seemingly insignificant but important conclusion that the forces between object and surface are independent of the contact area, hence without effect on the friction; placing a book flat or on its edge will not affect the friction. Leonardo’s interpretation of FLUID waves also gave him the crucial realization that the WAVE does not transport fluid in the direction of the wave propagation. He also concluded that SOUND is propagated by means of waves; although ARISTOTLE (c. 384–322 BC) stated in 350 BC that sound travels to the EAR through the AIR medium, he did not specify the wave phenomenon as such. The principles of sound waves were further refined by GALILEO GALILEI (1564–1642) in 1600. Leonardo was an Italian civil engineer, physicist, architect, and artist (proverbial Renaissance man). As an artist, he introduced realism in the observation and depiction of the HUMAN BODY. His artistic studies of bird flight led to his conceptual drawings of equipment that would allow man to fly. His scientific work showed in-depth understanding of the human BLOOD CIRCULATION mechanism.

He also elaborated on human sight and, in the same line of thought, alluded to the use of a CAMERA to capture a still frame (see [Figure D.1](#)).

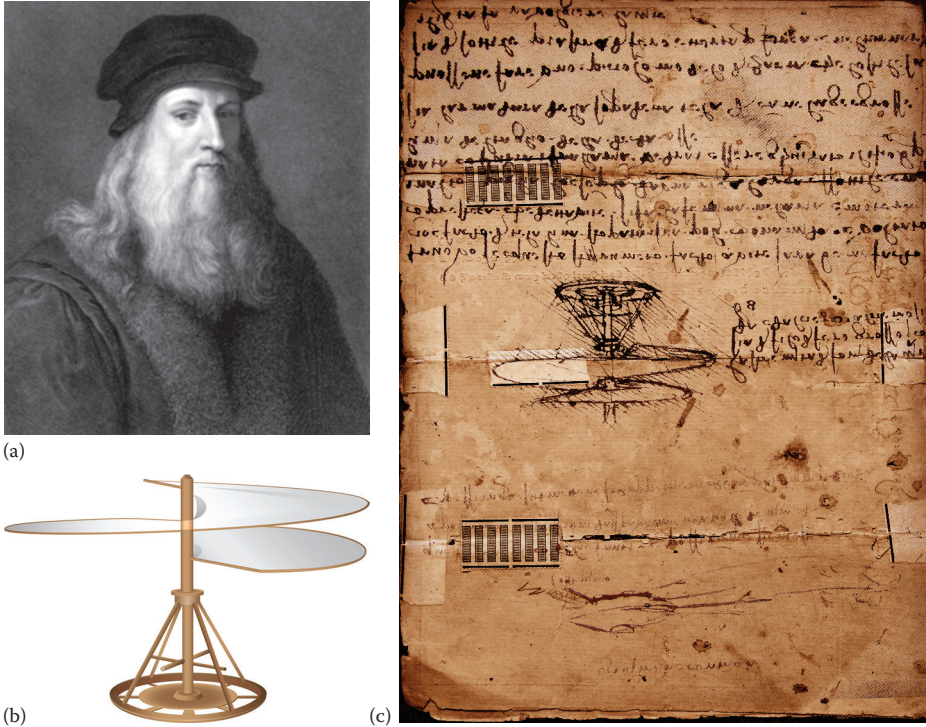


Figure D.1 (a) Leonardo di ser Piero da Vinci (1452–1519) the artist and scientist, with additional works representative of his insight into the geometry, anatomy, and science of people, objects, and devices, engraved by James Posselwhite; (b) design of a flight contraption, now called a plane, by Leonardo da Vinci; and (c) design of the helicopter concept based on the original ideas and drawings by Leonardo da Vinci.

Daguerre, Louis-Jacques-Mandé (1787–1851)

[optics] An artist and scientist from France. Louis Daguerre was instrumental in the invention and development of PHOTOGRAPHY (see [Figure D.2](#)).



Figure D.2 Louis-Jacques-Mandé Daguerre (1787–1851), photographed by Jean-Baptiste Sabatier-Blot.

Daguerreotype

[optics] A photographic IMAGE produced on a polished silver-plated sheet of copper, introduced in 1839 by LOUIS-JACQUES-MANDÉ DAGUERRE (1787–1851). The process was based on the CAMERA OBSCURA. The camera obscura was documented as created and first used by Mozi (c. 470–390 BC), a philosopher from China. Later in the sixth century, the Byzantine-Greek mathematician and architect Anthemius of Tralles (474–534 AD) describes the use of this mechanism for his work. The more established version was described by ROGER BACON (1214–1294), a scientist from Great Britain, during the observation of solar eclipses. The photosensitive material used was silver sensitized by iodine (see [Figure D.3](#)).

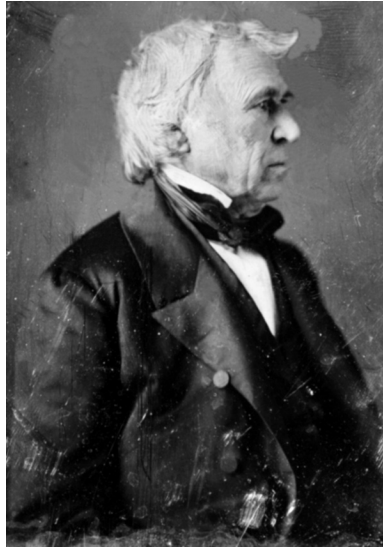


Figure D.3 Daguerreotype photograph of the 12th president of the United States: Zachary Taylor (1784–1850). (Courtesy of Mathew Brady.)

D'Alembert, Jean-Baptiste le Rond (1717–1783)

[computational] A mathematician from France. The work of d'Alembert was in the theoretical description of several PHYSICS phenomena, including FLUID DYNAMICS and equilibrium conditions, as well as in developing specific PARTIAL differential equations. Specific examples are the process of solving the one-dimensional WAVE EQUATION, inertia (potentially inspired by the laws of Newton, SIR ISAAC NEWTON [1642–1727], in the years 1743–1754), fluid dynamics (equilibrium conditions for fluid in MOTION, 1744), the motion of AIR (“wind,” 1745), and the partial differential equation for the wave on a string (one-dimensional wave equation, 1747). Additional work of d'Alembert was in the description of celestial ORBITS, specifically the deviations and obliquity of the elliptic trajectory and perturbations, the PRECESSION of the

equinoxes, and the general position of the EARTH in the SOLAR SYSTEM. The d'Alembert's paradox in fluid MECHANICS describes the fact that an object submerged in an inviscid, incompressible FLOW experiences no DRAG (see [Figure D.4](#)).



Figure D.4 Jean le Rond d'Alembert (1717–1783), engraved by W. Hopwood.

Dalton, John (1766–1844)

[atomic, chemical, energy, general, nuclear, quantum, thermodynamics] A scientist and school master from Great Britain. John Dalton was aware of the combination of ELEMENTS forming new structures (now known as MOLECULES), and with several elements known, he recognized that hydrogen was the lightest and assigned it the mass 1, which is still the accepted convention. He made attempts to construct a table of elements but was incorrect and incomplete. He did inspire the scientist DMITRI IVANOVICH MENDELEEV (1834–1907) from Russia to produce the PERIODIC TABLE OF ELEMENTS, which we currently use. Dalton was a contemporary of AMEDEO AVOGADRO, COUNT OF QUAREGNA (1776–1856), who in 1811 introduced the Avogadro number. In 1804, Dalton recognized that the relationship between the TEMPERATURE (T) and PRESSURE (P) for the boiling-point curve at the LIQUID-VAPOR equilibrium has a logarithmic dependency. This is clearly visible in the pressure versus temperature (P – T) PHASE DIAGRAM (see [Figure D.5](#)).



Figure D.5 John Dalton (1766–1844).

Dalton's law

[biomedical, fluid dynamics, thermodynamics] The sum of all the pressures (P) provided by the constituents of a GAS MIXTURE provides the total pressure; each component provides their respective partial pressure $P = \sum_{i=1}^N P_i$, where the partial pressure is the fractional component based on molar ratio (γ_m): $P_i = \gamma_{m,i} P$ (also see DALTON'S LAW OF PARTIAL PRESSURES).

Dalton's law of partial pressures

[thermodynamics] See DALTON'S LAW.

Damadian, Raymond Vahan (1936–)

[biomedical, computational, imaging] A scientist and mathematician from the United States, who also earned his medical degree in 1960. Damadian is the inventor of the nuclear MAGNETIC RESONANCE imaging modality in 1969. His research in tracking sodium and potassium during his appointment at SUNY (State University of New York) made him realize the potential of the imaging with magnetic fields. His research was partially based on the observations made during World War I where inanimate object exposed to strong alternating magnetic fields caused the nuclei to emit radiofrequency at characteristic wavelengths for the atomic structures involved. He discovered a change in RELAXATION TIME for radio-frequency emission from the nuclei of tissue cells resulting from pathological conditions, specifically cancer. It is now also a well-known fact that cancer cells have an enlarged NUCLEUS compared to the healthy equivalent.

Damage integral

[biomedical, energy] An estimation of the damage to material, chemical reaction, or biological tissue resulting from an insult. The PROBABILITY distribution is based on material properties and prior history of similar processes and materials. Generally, the insult involves the thermal response to exposure in excess of a verified threshold, or tiers or successive thresholds. When there are initially N_0 molecules of one species in a volume of medium (e.g., tissue), the number of surviving molecules is directly proportional to the native number, and the number of thermally altered molecules dN as a function of time can be shown to obey the following equation: $dN = k_r N dt$, where k_r is the reaction coefficient, specific for the molecules involved and generally a function of TEMPERATURE (T). The irreversible thermal changes to proteins are referred to as denaturation; boiling an egg provides the classic example, as is baking/grilling a steak or boiling milk. The number of surviving native molecules as a function of TIME (t) can be derived as $N(t) = N_0 e^{-\Omega(t)}$, where $\Omega(t)$ represents the damage integral. For both the egg and the steak, the thermal changes are clearly visible, as is the influence of time on the process. Another example is coagulation of collagenous tissue, which renders the collagen into gelatin, with the loss of collagen fiber bundle structure. The damage integral is defined by the ENTROPY (S) and ENTHALPY (H) of the "PHASE TRANSITION" or chemical transformation (e.g., denaturation). The damage integral is defined as $\Omega(t) = \int_0^t k_r(t') dt' = \int_0^t [k_B T(t')/h] e^{\Delta S/R} e^{-(\Delta H/RT(t'))} dt' = A_* \int_0^t e^{-(E_*/RT(t'))} dt'$, where R is the universal GAS constant (8.314×10^3 J/kmolK) and $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the BOLTZMANN COEFFICIENT. At any time during the thermal assault, the number of denatured molecules in the carbon-based medium, $N_{\text{denatured}}(t)$ [respectively chemically altered molecules: $N_{\text{change}}(t)$], equals $N_{\text{change}}(t) = N_0 - N(t)$. In general, the damage integral combines the average values for all molecular species involved in the denaturation process within a specific tissue volume. The rate constant k_r can have a dissimilar value for different transitions as a function of temperature and exposure time. Typical values of ΔS and ΔH for biological media as examples of thermal coagulation are listed in Table D.1. One common

Table D.1 Thermal denaturation parameters

TISSUE	ΔS (J/[MOL K])	$H \times 10^3$ (J/MOL)
Connective tissue	392	221
Muscle	510	259
Collagen	825	368

manner of setting the boundary conditions is to use the exposure time (t_Ω [s]) required to achieve $\Omega = 1$, which corresponds to $t_\Omega = 1/k_r$ as a function of the temperature. The more complex the molecular structures that are denatured, the sharper the rate constant that changes with temperature, because the change in entropy (ΔS) is greater as well as the number of bonds to be broken concurrently (ΔH) is larger in number. For the denaturation of a less-structured chemical matrix, the change in rate constant will proceed more gradually due to the fact that the changes in ΔS and ΔH do not respond as aggressive due to temperature. The choice of the change in enthalpy ΔH as the independent variable represents the concept of the ENERGY of all bonds that conjointly hold a molecular structure together. The entropy increase can be considered a dependent variable that describes the entropic energy change resulting from breaking the bonds.

Published data list the following average empirical values for SKIN tissue: $E_{*,\text{skin}} = 627 \text{ kJ/mol}$ and $A_{*,\text{skin}} = 3.10 \times 10^{98} \text{ s}^{-1}$; for collagen, the published values are, respectively, $E_{*,\text{collagen}} = 89 \text{ kJ/mol}$ and $A_{*,\text{collagen}} = 1.0 \times 10^{130} \text{ s}^{-1}$. The damage region $0 \leq \Omega(t) \leq 0.53$ is generally associated with no permanent damage or no damage at all to the tissue. The damage value in the range $0.53 < \Omega(t) < 5$ is associated with coagulation. Generally, the damage value $\Omega(t) < 1$ represents the creation of reversible tissue damage. The value $\Omega(t) = 1$ for biological media defines the point of onset of tissue coagulation, with a 63% probability of tissue denaturation. A value of $\Omega(t) = 4.6$ corresponds with a 99% probability of tissue denaturation. Tissue carbonization ("burning" the steak on the grill) can be considered to occur under the condition that the damage integral provides $\Omega(t) \geq 5$. Additionally, a second-degree burn can be indicated with $\Omega(t) > 10$, while a third-degree burn requires $\Omega(t) > 10,000$. Using these numbers to determine the time exposure required to obtain damage from skin exposure to 135°C resulting in a second-degree burn yields a value of approximately 150 s or 2.5 min, and a third-degree burn can be projected after an order of MAGNITUDE of 42 h (1 day and 18 h) total exposure. The damage integral is used to plan therapeutic procedures in clinical applications. One specific application is the removal of port-wine stain, while avoiding the formation of thermally generated scar tissue within the dermis. This can be accomplished by cooling the exterior, hence lowering the temperature and thus reducing the damage integral value for the dermis. For instance, laser heating of BLOOD vessels generates a high temperature transiently achieved subcutaneously from transdermal irradiation causing thermal damage to the vessel WALL and either shrinking of the vessel or eliciting clotting (thrombosis) within the vessel. The body's wound-healing response subsequently removes the clotted vessel, hence removing the port-wine stain lesion. Keeping in mind that irreversible damage to the skin tissue occurs at approximately 58°C or 60°C (short-term exposure). Comparatively, the instantaneous (i.e., less than a second) coagulation of blood does not occur until a temperature in the range 90°C to 100°C is achieved. This controversy makes avoiding unwanted thermal damage to the dermis difficult, even when selective wavelength choices that match the ABSORPTION SPECTRUM of blood are used (see Figure D.6).

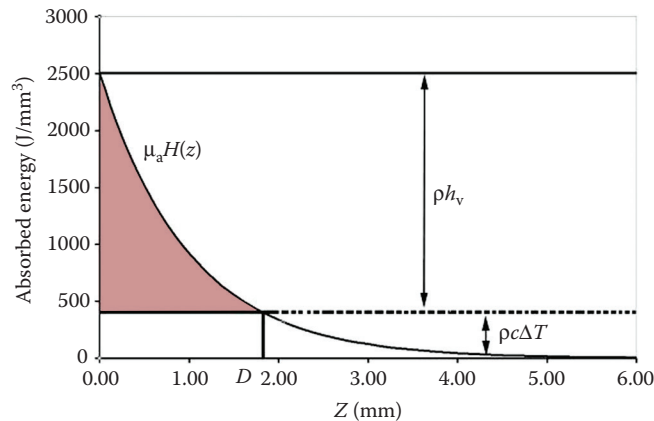


Figure D.6 Graphical illustration of the correlation between temperature and exposure to induce biological damage, represented under the damage integral.

Damage state

[biomedical, chemical, thermodynamics] The anticipated condition of the chemical reaction, and chemical and physical condition of a medium resulting from exposure to a certain temperature over an exposure time as described under the DAMAGE INTEGRAL. The damage state is generally determined as a discrete value, obtained over finite incremental steps in time. The damage calculation for time intervals of 0.1 s is, for instance, defined as $D_{\text{damage}} = \Omega(0.1) = 0.1A_{\text{th}} \exp(-E_{\text{th}}/RT)$, where $\Omega(t)$ is the damage integral, A_{th} and E_{th} are process constants (see DAMAGE INTEGRAL). On more general terms, the assumptions can be made $A_{\text{th}} = 3.1 \times 10^{98} \text{ s}^{-1}$ is the rate constant, and $E_{\text{th}} = 6.28 \times 10^5 \text{ J/mol}$ the activation ENERGY for burn injury. The total cumulative damage follows from repeating the summation successively over the total time of thermal exposure, for instance, the use of radio-frequency or laser assisted heating. Keeping in mind that, for the summation process, the thermal response may change due to increase or decrease in temperature by cumulative heating, conduction, and convection processes. As a consequence, the damage integral will need to be adjusted within the summation process. The following damage conditions for biological tissues can generally be identified: reversible damage to tissue or no damage at all under the damage state $0 \leq D_{\text{damage}} \leq 0.53$, irreversible coagulation $0.53 < D_{\text{damage}} < 1$, and carbonization (starting out from the exterior with black boundaries) for $1 \leq D_{\text{damage}}$.

Damköhler number

[chemical] Reaction quotient for scaling the dominant factors in a chemical process, DIFFUSION or reaction or both. The chemical reactions are related by $N_{\text{DA}} = \text{reaction rate}/\text{diffusion rate}$. The Damköhler number indicates the limiting factor; $N_{\text{DA}} \gg 1$ implies that the reaction is instantaneously at equilibrium, while $N_{\text{DA}} \ll 1$ means that the diffusion process will be at equilibrium well before the reaction process. Under condition of reaction rate proportional to the concentration of the bulk SOLUTION, the Damköhler number becomes $N_{\text{DA}} \sim k_{\text{R}} L^2 / \alpha D_{\text{AB}}$, where k_{R} is the rate constant, L is the characteristic length, α is the representative of the geometry of the situation ($\alpha = 1$ in most cases), and D_{AB} is the DIFFUSIVITY. The relevance of these types of approximations and estimations is, for instance, applicable to transdermal drug delivery, which is diffusion dominated. Another aspect comes into play when a process has a periodic (temporal or spatially cyclic) delivery sequence, as found, for instance, in the developmental process of the embryo, with both spatially cyclic and temporarily oscillating patterns of chemical concentrations. The oscillations, for instance, can be long term (hormonal) or short term (vasodilation/vasoconstriction). The Damköhler number may also be found as Thiele modulus, for instance, with respect to catalytic reactions.

Damped harmonic motion

[general, mechanics] An undamped harmonic oscillation relies on an ELASTIC RESTORING FORCE (HOOKE'S LAW: $F = kx$, where k is the spring constant and x is the displacement) without loss. Generally, there will be a loss factor, FRICTION (surface or FLUID: VISCOSITY), or heat production in the spring (or, for instance, elastic band), next to gravitational influences. An undamped FORCED OSCILLATION is governed by the following equation: for a spring $\nabla^2 u(\vec{r}) = (1/v^2)[\partial^2 u(\vec{r})/\partial t^2] - F$ and for a flexing (torsional) structure $\nabla^4 u(\vec{r}) + (1/\alpha^2)[\partial^2 u(\vec{r})/\partial t^2] = F$, where $\nabla^4 = \nabla^2 \nabla^2$ with $\nabla^2 = (d/dx^2) + (d/dy^2) + (d/dz^2)$ the Laplace operator, v is the speed of mechanical propagation in the structure, $u(\vec{r})$ is the displacement as a function of location, α is a parameter accounting for geometric and elastic influences (e.g., Young's modulus), and F is the applied force over time (t). Including dampening, for instance, the MOTION of a MASS (m) on a spring with the use of a DASHPOT with dampening factor b , in the spring system (e.g., a SHOCK ABSORBER) the WAVE EQUATION for the spring becomes a one-dimensional displacement $m(d^2 u/dt^2) + b(du/dt) + kx = F_0 \sin \omega t$, where $\omega = 2\pi v$ is the oscillation ANGULAR VELOCITY and v is the frequency for the applied force (note that a steady-state force will only stretch the spring). A damped

torsional VIBRATION (ANGLE of rotation: φ) for a homogeneous structure with uniform and constant density is described (in one-dimensional motion) resulting from an instantaneous torque providing an impulse: $(1/\alpha'^2)[\partial^2\varphi(\bar{r})/\partial t^2] - \sigma_1'^2(\partial^2\varphi(\bar{r})/\partial x^2) + \gamma_1(\partial\varphi/\partial t) - I^*r_i[\partial^3\varphi(\bar{r})/\partial x^2\partial t] = \xi_{ab}K_1e^{i\omega t}$, where α' is a ratio parameter accounting for geometric and elastic influences (e.g., YOUNG'S MODULUS) generally $\alpha' = 1$, $\sigma_1'^2 = cI^*$ is a coefficient linked to the moment of INERTIA, $\gamma_1 = \int_{x_1}^{x_2} \int_{t_1}^{t_2} r_e(x)/[\partial\varphi(x,t)/\partial t] dx dt$ is the dampening, where $r_e(x)$ is the coefficient of external DAMPING, r_i is the coefficient of internal damping, I^* is the moment of inertia per mass density, and K_1 defines the applied instantaneous torque. The total force is derived from the impulse Δp , where p is the momentum as $F = dp/dt$, with the impulse expressed as $p = \rho_\ell A_0 \int_{x_1}^{x_2} \int_{t_1}^{t_2} \xi_{ab}(x)e^{i\omega t} dx dt$, where ξ_{ab} represents the force ELEMENT, ρ_ℓ is the density per unit length, and A_0 is indicative of the AMPLITUDE. Torsional OSCILLATION can be found in drive shaft, McPherson Struts, the bowl of a wine GLASS when stuck with a rod, tennis racket (off-axis) hitting a ball, cricket bat (off-axis), and PROPELLER blade (more complex mechanism-of-action, however), to name but a few. A third class of oscillations with inherent dampening properties is in flexural oscillations with respect to displacement $u(\bar{r})$. The time-dependent displacement can be derived based on the following expression: $(1/\alpha''^2)[\partial^2 u(\bar{r})/\partial t^2] - \sigma_1''^2[\partial^2 u(\bar{r})/\partial x^2] + \beta_1'^2[\partial^4 u(\bar{r})/\partial x^4] + r_e''[\partial^2 u(\bar{r})/\partial x\partial t] + r_{ie}'(\partial u/\partial t) - r_{iu}'[\partial^3 u(\bar{r})/\partial x^2\partial t] - \gamma_i''[\partial^4 u(\bar{r})/\partial x^2\partial t^2] + r_{i2}'[\partial^5 u(\bar{r})/\partial x^4\partial t] = \xi_{ab}'K_1'e^{i\omega t}$, where α'' is a parameter accounting for geometric and elastic influences (e.g., Young's modulus) as a fraction most often $\alpha'' = 1$, $\sigma_1''^2$ is the coefficient of shear (function of internal deformation), $\beta_1'^2$ is the coefficient of the ratio of inertia to force, r_e'' is the coefficient of external damping, r_{ie}' is the coefficient of external damping at the extreme, r_{iu}' is the ratio of internal damping to tangential torque, γ_i'' is the coefficient of moment of inertia, r_{i2}' is the ratio of internal damping to inertia, ξ_{ab}' is the MAGNITUDE of the impulse, K_1' is the applied magnitude of instantaneous force, and ω is the ANGULAR VELOCITY. Since this describes a flexural oscillation, the applied force is generally an impulse, instantaneous, for example, hitting a tuning fork against a solid surface and jumping of a spring board at the swimming pool.

Damped motion

[general] A MOTION that is subject to restrictive external or internal forces, such as FRICTION, VISCOSITY, next to the ELASTICITY (YOUNG'S MODULUS) and COMPLIANCE of the materials used, as well as the interfaces between materials (see Figure D.7).

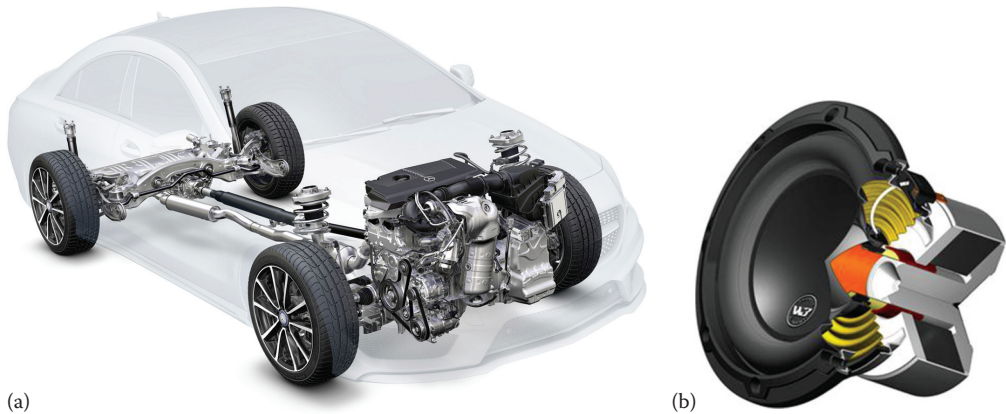


Figure D.7 Damped motion of the wheel on the axle of an automobile under influence of a pod: shock absorber, (a) automobile with shock absorbers at all four wheel attachments on the axles (Courtesy of Daimler AG) and (b) damped woofer. (Courtesy of Crutchfield, Charlottesville, VA.)

Damping

[general] A vibrational loss of AMPLITUDE due to conversion of ENERGY. An OSCILLATION can be underdamped with little loss of amplitude, critically damped yielding a pure exponential DECAY with oscillation, and overdamped providing a gradual decay in amplitude (see Figure D.8).

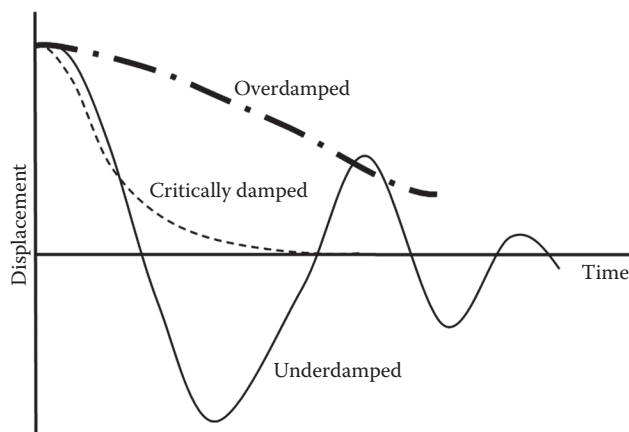


Figure D.8 Damping on harmonic motion.

Darcy's friction factor

[biomedical, fluid dynamics] In FLOW there are shear forces that result in LOSS OF HEAD (height that can be achieved by the flow, when flowing uphill), in addition to the loss resulting from discontinuities and shape changes such as found at fittings. The total HEAD LOSS in flow is the accumulated frictional loss ($b_{L, \text{friction}} = \sum K_L (v^2/2g)$, where K_L is the "minor-loss" coefficient (a material property), v is the average flow velocity, and g is the GRAVITATIONAL ACCELERATION) plus the "shape" loss ($b_{L, \text{shape}} = \sum f_D (\ell/D) (v^2/2g)$, where f_D is the Darcy's friction factor, generally obtained from Moody plots, ℓ is the length of the tube, and D is the main tube diameter) expressed as $b_{L, \text{total}} = b_{L, \text{shape}} + b_{L, \text{friction}}$. The total head represents the height (b) that can be achieved under Bernoulli's flow when flow of FLUID with density ρ is forced into a PIPE leaning uphill under pressure P and with flow velocity v : $P + (1/2)\rho v^2 + \rho g b$.

Darcy–Weisbach equation

[fluid dynamics] A formula used to calculate pressure or HEAD LOSS due to FRICTION in ducts, pipes, and tubes. In PIPE friction, the head loss (b_ℓ) can be expressed as $b_\ell = f_{\text{Moody}} (L/D) (v_{\text{avg}}^2/2g) = (\Delta P/\rho)$, where f_{Moody} is the MOODY FRICTION FACTOR, L is the pipe length, D is the pipe diameter, v_{avg} is the average flow velocity, g is the GRAVITATIONAL ACCELERATION, ΔP is the pressure drop, and ρ is the density of the FLUID in FLOW.

Dark field

[acoustics, imaging, optics] In regular microscopy, the sample under investigation is illuminated by a filled cone of light. In dark-field microscopy, the illumination is performed by means of a hollow cone. The apex of the cone is designed to fall at the location of the sample. When no sample is placed, the light will exit from the plane of the sample holder again as a hollow cone. The hollow cone of light will encapsulate the MICROSCOPE objective, however, without entering the objective. Once a sample is placed in the illuminated

plane at the apex of the cone, the light will scatter as a result of the particulate structure of the specimen. The IMAGE is made only from the rays of light that scatter from the specimen and enter the objective LENS. The dark image without specimen construes the “dark field.”

Dark matter

[astronomy/astrophysics, atomic, nuclear, quantum] A hypothetical cosmic substance that has been introduced to account for gravitational phenomena that require the presence of mass where no mass has been identified on a galactic scale. In practicality, the elusive dark matter does not interact with ELECTROMAGNETIC RADIATION (no light absorption or SCATTERING). The dark matter concept has overlapped with the concept of the “GRAVITON,” the gravitational particle. The principle of dark matter was introduced in 1932 by the Dutch astronomer JAN HENDRIK OORT (1900–1992). The dark matter is a substance that can account for the deviations in planetary and stellar ORBITS in the MILKY WAY that are apparently dependent on the presence of other planets; however, there is no observable evidence of those celestial objects. Some of the prevailing evidence supporting the existence of dark matter is the observed changes in galactic movement (the EXPANDING UNIVERSE), specifically by the Hubble TELESCOPE. The UNIVERSE has indication that is expanded more slowly some time back than it is today, the universe is accelerating. So far, the support for the existence of dark matter is purely based on theoretical analysis and still hypothetical. Based on these theoretical processes, more than 68% of the universe would consist of dark matter and only 5% is observable MATTER.

Dashpot

[general] A mechanical resistive device, for instance, by means of viscous FLOW through a porous structure under the influence of a moving piston or resulting from contact FRICTION. The equivalent in general MECHANICS is the use of a crumple zone in cars to absorb the ENERGY involved in a collision. The mechanical deformation provides the mechanism of conversion of kinetic energy in order to prevent exposure of the driver and passengers in the car to the full impulse (see Figure D.9).

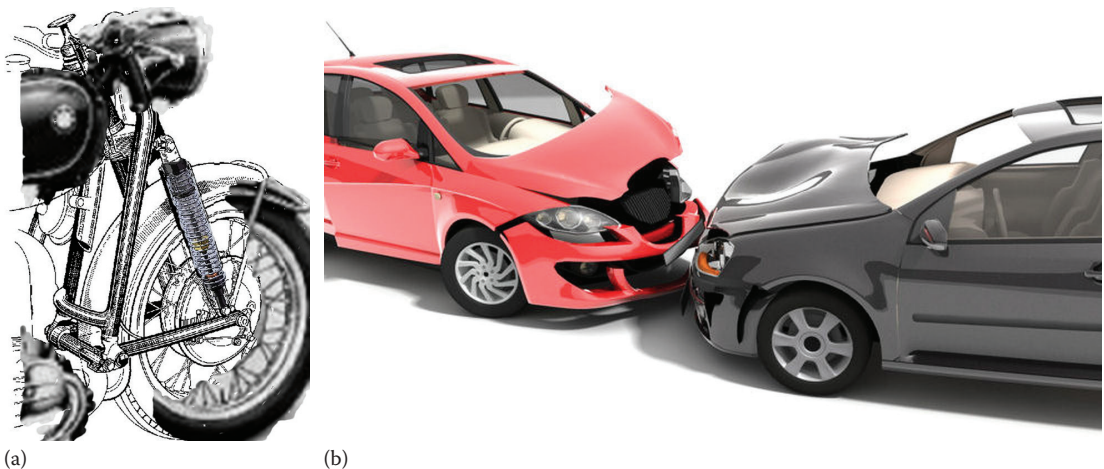


Figure D.9 (a) Dashpot dampener and (b) crumple zone of an automobile.

Daughter nucleus

[general, nuclear] A nuclide configuration resulting from atomic DECAY process. The parent–daughter process will emit a PARTICLE (e.g., helium ${}^4_2\text{He}$) and will release dissociation or disintegration ENERGY, defined by the rest MASS BALANCE ($Q_{\text{diss}} = m_X c^2 - m_Y c^2 - m_{\text{He}} c^2$, where $c = 2.99792458 \times 10^8 \text{ m/s}$ is the speed of light): ${}^A_Z X \rightarrow {}^{A-4}_{Z-2} Y + {}^4_2 \text{He} + Q_{\text{diss}}$.

Davis, Raymond Jr (1914–2006)

[nuclear] A physicist and chemist from the United States. The work of Raymond Davis on neutrinos resulted in the discovery of the antineutrino, which brought him the Nobel Prize in Physics in 2002.

Davisson, Clinton Joseph (1881–1958)

[computational] A physicist from the United States. In collaboration with LESTER HALBERT GERMER (1896–1971), Clinton provided conclusive evidence supporting de Broglie’s hypothesis of a WAVE phenomenon associated with moving MATTER in 1927 (see [Figure D.10](#)).



Figure D.10 Clinton Joseph Davisson (1881–1958). (Courtesy of Nobel Foundation, Stockholm, Sweden, 1937.)

Davisson–Germer experiment

[atomic, nuclear, quantum] An experimental observation made by CLINTON JOSEPH DAVISSON (1881–1958) and LESTER HALBERT GERMER (1896–1971) in 1925 verifying the postulated WAVE characteristics of any moving object. The observation was made somewhat accidental after the experimental setup had been modified due to a fire in the lab, in which the polycrystalline nickel target had been heated into a reformatted crystalline structure, at first unbeknownst to them. The initial experiment, prior to the explosion, had failed to show any conclusive evidence. During irradiation of the nickel crystal (new crystal) with an electron beam, a diffraction pattern similar to X-ray ELECTROMAGNETIC RADIATION was observed, hence verifying de Broglie’s hypothesis.

Davy, Humphry (1778–1829)

[general] A scientist who discovered attraction between a PERMANENT MAGNET and a current-carrying wire. The observation of Humphry Davy is tied in with the work of his contemporary ANDRÉ MARIE AMPÈRE (1775–1836) (see [Figure D.11](#)).



Figure D.11 Sir Humphry Davy (1778–1829). Portrait by Thomas Phillips; Copyright National Portrait Gallery, London: NPG 2546.

DC (direct current)

[general] Steady-state electrical phenomenon of moving charges.

De Benedetti, Sergio (1912–1994)

[nuclear] A physicist from Italy. The work of Sergio De Benedetti involved the description of the nuclear structure and ENERGY configuration, specifically the positron lifetime as well as the discovery of the POSITRONIUM.

De Broglie, Prince Louis Victor Pierre Raymond duc (1892–1987)

[computational, nuclear] A French mathematician and aristocrat. De Broglie gave an in-depth theoretical explanation of the WAVE properties of particles in 1923, electrons in particular, but also applicable to the nuclei: protons and NEUTRON (see [Figure D.12](#)).



Figure D.12 Prince Louis Victor Pierre Raymond duc de Broglie (1892–1987) in 1929.

De Broglie wave

[nuclear physics] A realization by LOUIS DE BROGLIE (1892–1987) in 1923 that all moving objects have a WAVE function associated with the movement with a WAVELENGTH (λ) that is the Plank's constant ($h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$) divided by the momentum ($p = mv$, m the object's mass and v its velocity) as $\lambda = (h/p) = (h/mv)$. The wavelength of any ENERGY form (PARTICLE or pure energy such as photons). For photons: $p = E/c$, where the ENERGY $E = h\nu$, is proportional to the FREQUENCY (ν) of the ELECTROMAGNETIC RADIATION. This concept ties in with the SCHRÖDINGER EQUATION for electrons, neutrons, and protons, as well as explains the movements of large objects. One specific application of the “de Broglie wave” theorem is in ELECTRON MICROSCOPY, providing a RESOLUTION associated with the electron bombardment that fits the RAYLEIGH CRITERION.

De Fermat, Pierre (1601–1665)

[computational, general, optics] A French mathematician, *see* FERMAT, PIERRE DE (see [Figure D.13](#)).



Figure D.13 Pierre de Fermat (1601–1665).

De Forest, Lee (1873–1961)

[atomic, electronics, nuclear] An inventor and scientist from the United States. In 1906, Lee de Forest invented the triode VACUUM tube and realized the opportunities for SIGNAL amplification with this device. He perfected the vacuum tube concept as invented by SIR JOHN FLEMING (1849–1945). His work proceeded to move him into RADIO transmissions, specifically establishing radio broadcast stations. He is also credited for adding SOUND to movies, ending the “silent movie” period (see [Figure D.14](#)).

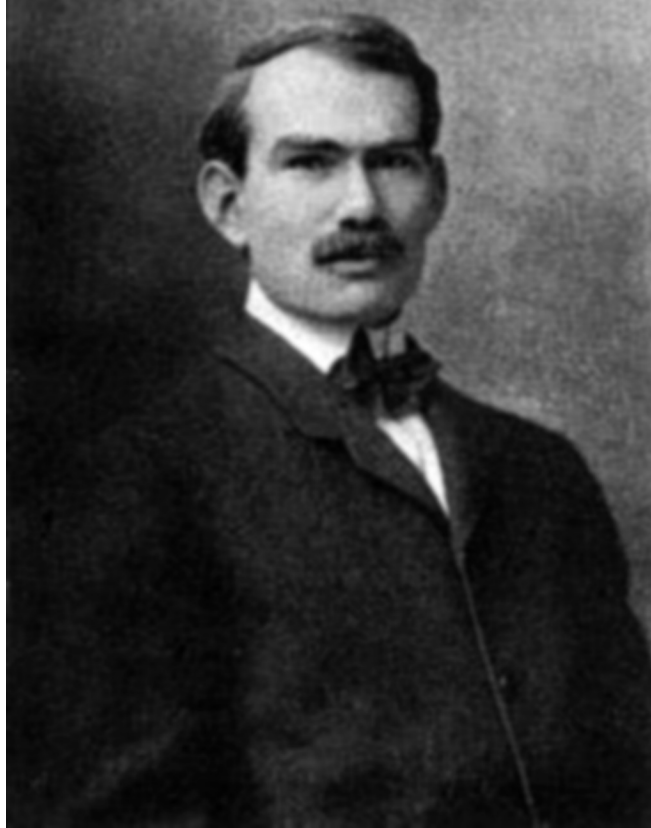


Figure D.14 Lee De Forest (1873–1961) as published in the 1904 issue of “The Electrical Age.”

De la Tour, Charles Cagniard, Baron (1777–1859)

[general] An inventor from France who introduced the “siren” in 1819, based on his analogy between the legend of the sirens and the initial invention of the Scottish mathematician and scientist JOHN ROBINSON (1739–1805) in 1801. Robinson’s invention produced puffs of AIR that, when blown through holes on a rotating disk, would create a SOUND that he equated to the VOICE of a woman singing. De la Tour managed

to repeat the process with a similar device under water, and hence, the analogy with the Greek mythology sea-nymphs was made (see [Figure D.15](#)).



Figure D.15 Baron Charles Cagniard de la Tour (1777–1859).

De la Vallée-Poussin, Charles-Jean Étienne Gustave Nicolas, Baron (1866–1962)

[computational] A mathematician and physicist from Belgium. De la Vallée-Poussin is known for proving the prime-number theorem in 1896. His other work was in approximation theory.

De Laval, Karl Gustaf Patrik (1845–1913)

[fluid dynamics] A scientist and inventor from Sweden. De Laval made significant contributions to the design and operations of steam turbine MACHINES as well as several devices used in the dairy industry. One specific device is the milk separator, separating cream from milk under high volume processing. Other contributions include improvements to milking machines (commercial introduction in 1918) and injection nozzles (see [Figure D.16](#)).

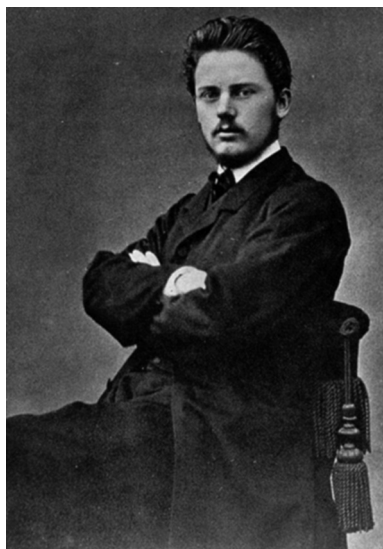


Figure D.16 Karl Gustafs Patrik de Laval (1845–1913), 1875.

De Laval nozzle

[fluid dynamics] A NOZZLE introduced based on the fluid-dynamic analysis by GUSTAF DE LAVAL (1845–1913) used in rocket engines. The specific design of the De Laval nozzle guides pressurized GAS from subsonic to SUPERSONIC FLOW velocity resulting in optimal ENERGY conversion from the heated entry gas to kinetic flow velocity using a choked flow condition. The De Laval nozzle was initially designed for steam turbines and later found perfect applications in super-sonic JET engines (see [Figure D.17](#)).

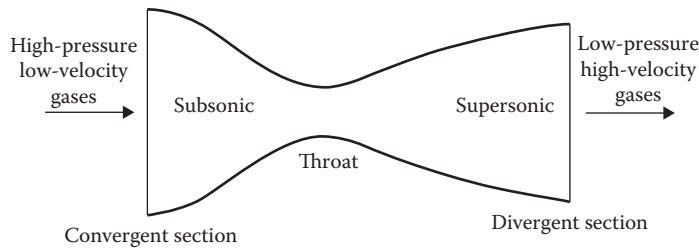


Figure D.17 De Laval nozzle.

De Maricourt, Pierre (1220–1290)

[electromagnetism, solid-state] A French engineer that described the use of metallic needles that were placed on the surface of a spherically polished LODESTONE (naturally magnetic material) the METAL silvers aligned themselves with the MAGNETIC FIELD lines running from pole to pole, while at the pole they would stand erect. In record books, de Maricourt is also named as Petri Peregrinus (*also* Peter de Pilgrim). The meridian circles formed by connecting the positions with equal magnetic force would converge at the respective opposing POLES, where the magnetic field is the strongest (primarily because the field-line density is the highest here). While MAGNETISM was supposedly known since the thirteenth century BC, as was the interaction between magnetic particles and metals, no formal description of the magnetic path was described in detail.

De Medicina

[biomedical] The medical encyclopedia assembled by the Egyptian scholar CELSUS. (second century AD). De Medicina is the most complete known work describing the medical knowledge acquired during the Alexandrian Empire.

De Mondeville, Henri (1260–1320)

[biomedical, chemical, optics] A French physician who reportedly used RED light in the earlier recorded attempts of using light to treat medical conditions, in this case the treatment of smallpox. The Danish physician NIELS RYBERG FINSEN (1860–1904) built on this initial endeavor in the early

1900s when he received the Nobel Prize for his work on the treatment of smallpox with light in 1903 (see [Figure D.18](#)).

CHIRURGIE

DE

MAITRE HENRI DE MONDEVILLE

CHIRURGIEN DE PHILIPPE LE BEL, ROI DE FRANCE

COMPOSÉE DE 1306 A 1320

TRADUCTION FRANÇAISE

AVEC DES NOTES, UNE INTRODUCTION ET UNE BIOGRAPHIE

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AVEC LA COLLABORATION

DE D^r SAINT-LAGER ET DE F. CHAVANNES



Ce monument de la Chirurgie française méritait
de trouver sa place parmi ceux des prédécesseurs
de Guy de Chauliac.
LITTAZ, *Histoire* t. XXVIII, p. 324



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Figure D.18 Title page of the manuscript written by Henri de Mondeville in 1306. (Courtesy of Bibliothèque de France, Paris, France.)

De V. Weir, John B.

(surname potentially: Weir de Vere (de Vere), Weir; twentieth century scientist; no additional personal information available) [biomedical, thermodynamics]: an engineer and physiologist from Scotland, Great Britain, who derived the relationship between the conversion of oxygen to carbon dioxide (CO₂) and the

generated heat and CHEMICAL ENERGY, specifically applied to the METABOLISM of the HUMAN BODY, published in 1948. The total ENERGY (E_{Ox}) released per VOLUME (V) oxygen ($[O_2]$) was empirically found to obey $E_{Ox} = 3.941 + 1.106 \log(V_{CO_2}/V_{O_2})$, expressed in kcal/liter O_2 . This equation was later corrected to incorporate the influence of proteins, measured by means of the production of urinary nitrogen ($[N]$, in urinary solution U_N): $E_{Ox} = 3.941 + 1.10E_{Ox} = 3.941 + 1.106 \log(V_{CO_2}/V_{O_2}) - 2.170(U_N/V_{O_2})$. The WEIR EQUATION is a standard in biomedical CALORIMETRY.

Dead state

[thermodynamics] A description of the environmental conditions pertaining to a system within a reservoir where no ENERGY is exchanged, nor added. This situation will never support work or chemical reactions, no useful efforts (*also* PASSIVE STATE).

Dead zone

[acoustics] A region in underwater acoustic imaging where there is no discrimination possible between objects and life forms with respect to the sea bottom. The dead zone height (h_{dz} ; DISTANCE from the bottom that cannot be resolved acoustically) calculations can apply, for instance, to the location of concentrations of fish. The imaging constraints are a function of the operational pulse duration (τ_p), the depth at which the bottom of the body of water resides (d_B), the viewing ANGLE (θ) for determination of the school of fish with respect to the acoustic axis, and the speed of SOUND of the WATER (v_s), expressed as $h_{dz} = d_B(1 - \cos \theta) + (v_s \tau_p / 2)$.

Dean, William Reginald (1896–1973)

[fluid dynamics, mechanics] A scientist from Great Britain. The work of William Dean involved FLOW at low REYNOLDS NUMBER. Specific research provided details about the perturbations in an otherwise LAMINAR flow process resulting from a gap in the WALL of a PIPE. His main contributions to the understanding of flow were with respect to the turbulent effect in curved tubes.

Dean equations

[biomedical, fluid dynamics] FLUID flow equations under low REYNOLDS NUMBER defined by WILLIAM REGINALD DEAN (1896–1973) in 1928. The FLOW equations for a tube with slight curvature R and radius a were subjected to PRESSURE (P) gradient $P_G = -(1/r)(\partial P / \partial \phi)$, expressed in cylinder coordinates. The use of cylinder symmetry of the tube makes the cylinder coordinates useful (r, ϕ, z). The system is defined by flow velocity $\vec{u} = (u_r, u_\phi, u_z)$ with MAGNITUDE ("reasonable value") $U_f \cong P_G a^2 / \eta_{\text{dyn}}$, where η_{dyn} is the dynamic VISCOSITY. Consider only the torus portion of the cylinder $(r-b)^2 + z^2 = a^2$, where $b \gg a$, scaling $r = b + ax^*$. Under entry LAMINAR FLOW, the down-pipe flow velocity distribution is $v(r) = 2v_{\text{max}}[1 - (r^2/a^2)]$. The flow process can be described as follows: $Dn[(Du_x^*/Dt) - u_\phi^{*2}] = -Dn(dP/dx^*) + \nabla^2 u_x^*$, where $Dn = \text{Re} \sqrt{(2a/2R)} = (L\rho v / \eta_{\text{dyn}} g) \sqrt{(2a/2R)}$ the DEAN NUMBER, with L the PIPE length, and the convective derivative $(D/Dt) = (\partial/\partial t) + u_r(\partial/\partial r) + u_z(\partial/\partial z)$, $u_{r,z}^* = v_{r,z}/U_f \sqrt{(a/R)}$, $u_\phi^* = u_\phi/U_f$, and $u_z^* = u_z/U_f$ the axial velocity. Additional expressions in the Dean equations are $Dn(Du_\phi^*/Dt) = 1 + \nabla^2 u_\phi$ and $Dn(Du_z^*/Dt) = -Dn(\partial P/\partial z) + \nabla^2 u_z^*$, under boundary condition $(\partial/\partial x)u_x^* + (\partial/\partial y)u_z^* = 0$. The Dean equations have close similarity to the NAVIER-STOKES EQUATIONS, in this case specifically applied to a NEWTONIAN FLUID flow in a toroidal pipe with a steady axially uniform flow profile. For pipe configuration with small radius of curvature in the flow, the Dean number can be expanded in a series ($Dn < 956$, above this number the solutions tend to become unstable), reducing the mathematical complexity.

Dean number ($Dn = \text{Re} \times \sqrt{(D/2R)}$)

[energy, fluid dynamics] An indication of the influence of the CENTRIPETAL FORCE on the FLOW pattern for flow in a curved pipe, where Re is the REYNOLDS NUMBER, D is the diameter of the PIPE, and R is

the radius of curvature of the curved pipe. It was introduced by WILLIAM REGINALD DEAN (1896–1973) in 1927. The phenomenon has similarity with the CORIOLIS EFFECT.

Dearnaley, Geoffrey (1930–2009)

[electronics, nuclear, solid-state, thermodynamics] A physicist from Great Britain. Geoffrey Dearnaley provided significant insight into low-energy nuclear PHYSICS, next to ION channeling processes. His additional efforts were in semiconductor impregnation process development and semiconductor construction (see [Figure D.19](#)).



Figure D.19 Geoffrey Dearnaley (1930–2009). (Courtesy of Southwest Research Institute, San Antonio, TX. Copyright SwRI.)

Debakey, Michael Ellis; born "Dabaghi" (1908–2008)

[biomedical, fluid dynamics, mechanics] A surgeon and scientist from the United States who significantly improved on the operations and functionality of the roller PUMP. The roller pump is a machine that circulates BLOOD and other fluids without significant risk to the integrity of the constituents, specifically not damaging RED blood cells. The mechanism of action is a PERISTALTIC MOTION. The FLUID is transported through a tube using the Bernoulli principle and the mechanical advancement of an enclosed segment of LIQUID in a tube by means of a set of rollers that are critically spaced to continuously keep an amount of liquid trapped for transport, which is based on the tube diameter. The alternatives are piston pump or diaphragm pump. Since the tubing can be removed and constitutes an ISOLATED SYSTEM, the peristaltic roller pump has all the conditions for sterility and safety in place. The roller pump is an essential tool in cardiac bypass surgery, known as the HEART–lung machine. Michael DeBakey is also known for his pioneering efforts in bypass replacement surgery, implanting Dacron® grafts to replace occluded coronary

vessels. He was also instrumental in the development of the first artificial heart and subsequent device design improvements and surgical implant procedures (see [Figure D.20](#)).



Figure D.20 Michael DeBakey (1908–2008).

Deborah number ($De = t_f |\vec{v}|/L$)

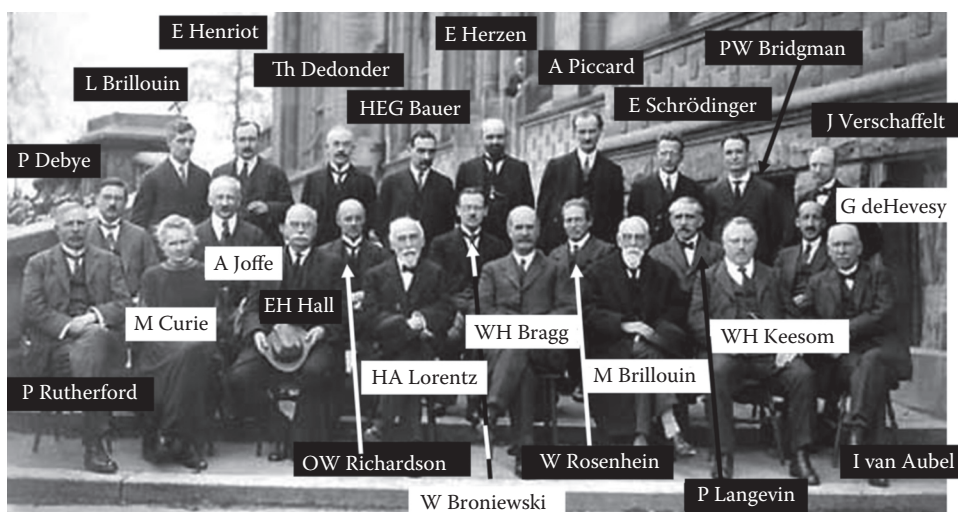
[fluid dynamics] A dimensionless number used in VISCOELASTIC (i.e., non-Newtonian) FLOW to scale the deformation rate for nonconstant stretch, in which case ENERGY is stored and released in the elastic format. The Deborah number is used to describe the ratio of the RELAXATION TIME to the flow timescale $De \sim t_r/t_f$, where $t_f = \sqrt{(\text{tr}(\dot{\epsilon}))^2/2} = \text{tr}(\dot{\epsilon})/\sqrt{2}$ describes the flow timescale, tr denotes TRACE, $\vec{v}$ is the flow velocity, and L is the PIPE length or characteristic size of the phenomenon (over which the elastic energy is stored or released). The flow timescale is dependent on the strain rate $\dot{\epsilon}$ (strain: ϵ), which is defined by the flow velocity as $\dot{\epsilon} = \nabla \vec{v} + (\nabla \vec{v})^T$, where T is the transposed matrix. The Deborah number becomes important when the flow timescale is less than the relaxation time (τ_r) and elastic effects become dominant. For a steady low REYNOLDS NUMBER shear flow, the flow time factor is a function of the shear rate ($\dot{\gamma}$): $t_f = 1/\dot{\gamma}$, whereas the flow timescale for extensional flow is $t_f = 1/\epsilon$, where ϵ is the extension rate or strain of the flow. The WEISSENBERG NUMBER is closely related to the Deborah number ($De = t_f |\vec{v}|/L = Wi (D/L)$), where D is the diameter of the phenomenon or tube diameter).

Debye, Petrus (Peter) Josephus Wilhelmus (1884–1966)

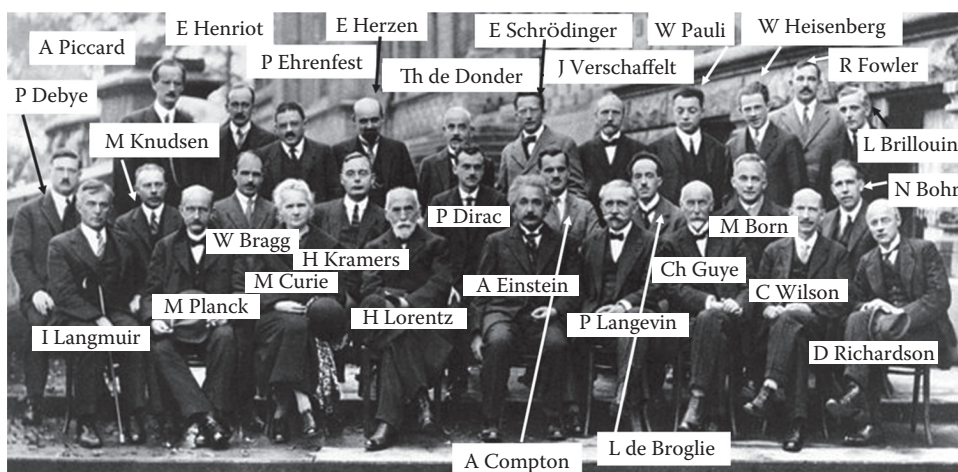
[general, thermodynamics] A electrical engineer, physicist as well as physical chemist from the Netherlands. Debye's work on heat capacity of solids provided him with the Nobel Prize in Chemistry in 1936, and he received various other awards (e.g., Max Planck Medal in 1950; Priestley Medal of the American Chemical Society in 1963, and Kommandeur des Ordens Leopold II in 1956). Professor Debye moved to the United States in 1940 after working at many renowned European universities (see [Figure D.21](#)).



(a)



(b)



(c)

Figure D.21 (a) Petrus (Peter) Josephus Wilhelmus Debye (1884–1966). (Courtesy of Museum Boerhaven, Leiden, the Netherlands.) (b) Courtesy of Solvay conference 1924 “Electrical Conductivity of Metals and Related Problems.” (c) Courtesy of Solvay conference 1927: “Electrons and Photons.”

Debye (D)

[electromagnetism, general] A unit for DIPOLE moment attributed to and named in honor of PETER DEBYE (1884–1966), expressed in a derivative of the SI UNITS, in CENTIMETER gram seconds (CGS) units. The unit transforms as $1D = (1/299792458) \times 10^{-21}$ cm.

Debye equations

[mechanics] The relationship between force and static stress (CREEP) that determines the region of ANELASTICITY (i.e., NONELASTIC behavior) for a medium, expressed as a function of the complex COMPLIANCE $J^* = \text{strain}/\text{stress} = \epsilon_s/\sigma_s = J_1 - iJ_2$. For a cyclic LOAD with ANGULAR FREQUENCY ω , this provides the Debye equations: $J_1 = J_U + [(J_R + J_U)/(1 + \omega^2\tau^2)]$, where τ is the relaxation time, and $J_2 = (J_R - J_U)[\omega\tau/(1 + \omega^2\tau^2)]$. This is connected to the material conditions as $J_R\sigma_s + \tau J_U(d\sigma_s/dt) = \epsilon_s + \tau(d\epsilon_s/dt)$. The imaginary part of the compliance (J_2) lags the STRESS (σ_s) by $\pi/2$. The anelastic behavior is described by the creep defined by $\epsilon_s(t)/\sigma_0 = V + (J_R - J_U)[1 - \exp(-t/\tau)]$, where σ_0 is a static stress (creep). Plotting this expression as a function of time will illustrate a discontinuity at the moment the external force is removed. The Debye relations illustrate a form of DAMPING. When plotting the imaginary part (J_2) of the Debye functions against $\log \omega\tau$ will yield a graph that is symmetric around a point, referred to as the Debye peak. Under thermally activated processes, the Debye peak associated with the anelastic behavior will shift over time with TEMPERATURE (T) according to $\tau = \tau_0 e^{Q_{ch}/k_B T}$, where τ_0 is the steady-state SOLUTION for the RELAXATION TIME, Q_{ch} is the chemical activation ENERGY, and $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the Boltzmann coefficient.

Debye expression

[quantum] A definition of the SPECIFIC HEAT of a solid based on QUANTUM THEORY, defined as $C_P(T) = 3RD(\xi)(T/\theta_D)$, where $C_P(T)$ is the specific heat at constant pressure, θ_D is the “Debye temperature” with $D(\xi) = 12\xi \int_0^{1/\xi} [x^2 dx / (e^x - 1)] - [(3/\xi)/(e^{1/\xi} - 1)]$, and R is the universal GAS constant.

Debye length (λ_D)

[thermodynamics] The confinement requirement for unneutralized plasmas $\lambda_D = \sqrt{(k_B T / 4\pi e^2 n)} = \sqrt{(\epsilon_0 k_B / e^2) / [(n_e/T_e) + \sum_{ij} j^2 n_{ij}/T_i]}$, where $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the Boltzmann coefficient, T is the PLASMA temperature in KELVIN, respectively, T_i is the ION temperature and T_e is the electron temperature, $e = 1.60217657 \times 10^{-19}$ C is the electron charge, and n is the number of components (electrons and ions), respectively, n_e is the plasma electron density and n_{ij} is the density of all the various ions with charge j , and the permittivity of free space: $\epsilon_0 = 8.85419 \times 10^{-12}$ C²/Nm². The pressure requirement for separation at the Debye length is standard thermal pressure $P = nk_B T$. Also found as $\lambda_D = 69\sqrt{(KE/n_e)}$, where KE is the KINETIC ENERGY of the ELECTRON, and n_e is the electron density.

Debye sphere

[nuclear, thermodynamics] The confinement for plasma PHYSICS, describing the interaction between ions and electrons (SCATTERING), outlined by the DEBYE LENGTH $\lambda_D = \sqrt{(k_B T / 4\pi e^2 n)}$, where $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K is the Boltzmann coefficient, T is the temperature in KELVIN, $e = 1.60217657 \times 10^{-19}$ C is the electron charge, and n is the number of components (electrons and ions). The collision time (τ_c) for the large PARTICLE population within the DEBYE SPHERE (N), at temperature T , under particle density n , for ions with mass m with charge Ze (electron charge $e = 1.60217657 \times 10^{-19}$ C) is $\tau_c = m^{1/2} (3k_B T)^{3/2} / 8\pi n Z^4 e^4 \ln \Lambda$, where $\ln \Lambda \sim \ln N$ represents the collision PROBABILITY.

Debye streamers

[nuclear, thermodynamics] Corona channels of ionized material (electrons and ions) traveling in a confined current density that acts as a screen to external electric and magnetic fields, as sheaths

(i.e., Coulomb shielding). The sheaths have a “thickness” in the order of the DEBYE LENGTH ($\lambda_D = 69\sqrt{T_e/n_e}$, where T_e represents the electron temperature of the PLASMA and n_e is the electron density. These streamers form in the time frame defined by the PLASMA FREQUENCY ($\nu = \omega/2\pi = 8.97\sqrt{n_e}$). For a VACUUM tube filament discharge corona, this translates in an electron density range $10^{18} < n_e < 10^{21} \text{ m}^{-3}$, with associated applied potential resulting in $T_e = 1.0 \text{ eV} \sim$ (INFRARED light), and this will yield $7.4 \times 10^{-6} < \lambda_D < 2.0 \times 10^{-7} \text{ m}$ over a discharge timescale of $1.1 \times 10^{-10} < 2\pi/\omega < 3.5 \times 10^{-12} \text{ s}$. For a thunderstorm with LIGHTNING, this may be in the range of $T_e = 4 \times 10^4 \text{ K} = 3.6 \text{ eV}$ (visible light), with currents in excess of 30 kA, with the discharge lasting in the order of $1 \times 10^{-4} \text{ s}$. During discharge, the electrons travel at several thousand times the DRIFT VELOCITY ($v_{\text{drift}} \sim 10^{-6} \text{ m/s}$; $v_{e,\text{discharge}} \sim 10^3 \text{ m/s}$), as do the ions, reaching in excess of $v_{\text{ion,discharge}} \sim 10^1 \text{ m/s}$. Next to lightning, the phenomenon of “dry discharge” under St. Elmo’s fire falls in the same category but the conditions are different due to the static buildup of charge and the narrow spike (e.g., ship’s mast) that forms the wide-spread spray of discharges with limited confinement (see Figure D.22).

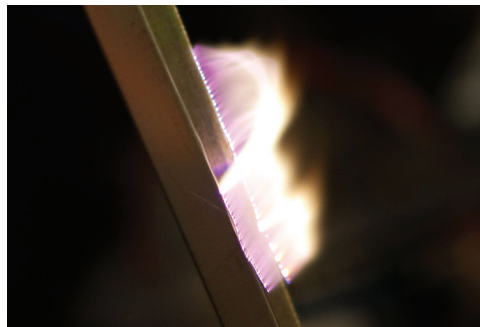


Figure D.22 Example of Debye streamers; plasma Jacob’s ladder. (Courtesy of “Chocolateak.”)

Debye temperature (Θ_D)

[thermodynamics] A thermal coefficient that defines the TEMPERATURE (T) dependence of the SPECIFIC heat under constant volume (c_V) and provides the approximation under condition $T \gg \Theta_D$: $c_V \approx 3R \left[1 + (1/20)(\Theta_D/T)^2 \right]$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant, named after PETRUS DEBYE (1884–1966). The Debye temperature has been tabulated for a range of media.

Debye–Scherrer equation

[atomic, imaging, nuclear] See SCHERRER EQUATION. It was introduced by PAUL SCHERRER (1890–1969), and experimental verification was supported by PETER DEBYE (1884–1966).

Debye–Scherrer method

[atomic, imaging, nuclear] An X-RAY crystallographic study where the medium is GROUND up for analysis, in contrast to the Bragg and Laue method that uses the single crystal. Debye–Scherrer method was named after PETER DEBYE (1884–1966) and PAUL SCHERRER (1890–1969) and was proposed in 1916. The analysis applies a narrow parallel beam of monochromatic X-ray. Interaction with the crystalline powder produces a series of coaxial X-ray diffraction CONES, with the incident BEAM FORMING the central axis. The apex ANGLES of the respective cones are determined from the Bragg diffraction rule: $n\lambda = 2d \sin \theta$ (where n is a positive integer, λ is the wavelength of the X-rays, d is the DISTANCE between the parallel planes [interplanar spacing] of the points of the space crystal LATTICE, and θ is the angle between the reflecting plane and the incident beam). Under these conditions, the REFLECTION angle (ϕ) is one-fourth of the cone’s apex angle. The diffraction pattern is captured on a PHOTOGRAPHIC PLATE, or scintillographic digital recording, providing the tools for derivation of the distance of the interplanar distance.

Decay

[nuclear] The disintegration of the NUCLEUS of an unstable ELEMENT by the spontaneous emission of charged particles and/or photons (*see* RADIOACTIVE DECAY and COMPOUND NUCLEUS).

Decay constant ($\lambda_{1/2}$)

[atomic, biomedical, computational, general, nuclear] The change in the number of isotopes of reactive atoms N over TIME (t) with respect to the original quantity by half $\lambda_{1/2} = (\Delta N / \Delta t) / N$, units $1/s$ or s^{-1} . This is a fixed value for any specific ELEMENT or ISOTOPE. This rewrites as $N = N_0 e^{-\lambda_{1/2} t}$, where N_0 is the base quantity.

Decay rate (R)

[general] $R = (1/2)^n R_0$, where $R_0 = \lambda_{1/2} N_0$, $\lambda_{1/2}$ is the DECAY constant, N_0 is the original quantity of radioactive nuclides, and n is the number of half-lives: $\tau_{1/2} = 1/\lambda_{1/2}$, or the total disintegration time period.

Decibel

[acoustics, biomedical, electronics, general, imaging, optics] The log of intensity (I), primarily used for quantifying relative signal MAGNITUDE, used in ELECTRONICS, ACOUSTICS, OPTICS (specifically as a material property [specification] for fiber optics), and IMAGE processing. DECIBEL was named after the Scottish inventor and scientist ALEXANDER GRAHAM BELL (1847–1922) and was introduced at the Bell laboratories. The decibel scale has two separate definitions: $dB = 10 \log I / I_0$, where I_0 is a reference intensity. Under these conditions, double the intensity equates to a 3dB increase. Alternatively, in acoustics, the magnitude may be measured in PRESSURE (P) $dB = 20 \log (P_{RMS} / P_0)$ (note that intensity is equal to the square value of the magnitude: $I \sim P^2$), where in AIR $P_0 = 2.0 \times 10^{-5}$ Pa and in water $P_0 = 1 \times 10^{-6}$ Pa, respectively. In biomedical acoustics (HEARING), the reference level is the threshold for hearing $I_0 = 1 \times 10^{-12}$ W/m². The threshold for pain with respect to human hearing is in the order of 120 dB across the entire audible FREQUENCY SPECTRUM, whereas the hearing limit is at its lowest threshold for 3000 Hz. The human hearing, as well as that for other mammals, has an enormous dynamic range, in the order of 10^{14} . The decibel is used in quality control as a threshold for acceptance or in quantifying degradation of SIGNAL strength and MAGNITUDE in general.

Defibrillator

[biomedical] An electronic device used to apply a short-duration, high-current, single-pulse electrical discharge to the HUMAN BODY in order to depolarize the HEART MUSCLE and attempt to reinitiate the DEPOLARIZATION sequence in normal order. The heart is composed of the atria and ventricles, which can, as a result of medical and chemical (e.g., cocaine) conditions, reach a high rate of depolarization. The high depolarization rate will force the heart to contract at rates that are not conducive to the COMPLIANCE of the vasculature, resulting in a “no-flow” condition. Arrhythmias may result in death when not properly attended to. Ventricular fibrillation or ventricular tachycardia (the high rate of depolarization; arrhythmia) is more directly linked to the whole-body FLOW, whereas atrial fibrillation will result in poor ventricular filling, ensuing poor ventricular outflow (*see* Figure D.23).



Figure D.23 Image of cardiac defibrillator.

Deflagration

[chemical, energy, fluid dynamics] A subsonic combustion propagating by THERMAL CONDUCTIVITY. The addition of water to specifically OIL that is being incinerated will result in the formation of water VAPOR, which adheres oil droplets that are ejected into the flames, causing the flames to erupt in a pyrogenic fireworks display.

Degeneracy

[atomic, computational, nuclear, quantum, thermodynamics] In QUANTUM MECHANICS, the degeneracy of a state outlines the entropy of the GROUND STATE, defined as $S_g = k_B \ln D_g(n, \beta)$, where $D_g(n, \beta)$ is the degeneracy that ties in to the SECOND and THIRD LAW OF THERMODYNAMICS, signifying that a state is nondegenerate when $D_g(n, \beta) = 1$ for all values of the number of constituents (n) and a range of parameters (β) (including but not limited to volume, pressure, and temperature), and $k_B = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the Boltzmann coefficient. The nondegenerate state implies that there is only QUANTUM STATE for one particular ENERGY value. In contrast, an energy value is degenerate if it is shared between multiple quantum states. The computational equivalence is that a nondegenerate state only has one EIGENFUNCTION as SOLUTION to the Schrödinger equations.

Degenerate state

[atomic, computational, nuclear, thermodynamics, quantum] the computational principle of a degenerate state is that more than one EIGENVALUE exists for the Hamiltonian at one condition. In quantum PHYSICS, this translates into a condition where one ENERGY state has more than one QUANTUM STATE, captured by multiple solutions for the eigenfunctions of the Schrödinger equations.

Degrees of freedom

[atomic, general, nuclear, solid-state, thermodynamics] The potential MOTION capabilities of a system, rotation of an object on its own axis, rotation around a centralized object, translation, acceleration, as well as PRECESSION, and the fact that an elliptical orbit can “swing” around one of the focal positions (found to apply to nuclear ORBITS in QUANTUM PHYSICS). The latter is captured by the “FINE-STRUCTURE CONSTANT,” for instance, applied to the ZEEMAN EFFECT and other spectral phenomena.

Delayed neutron

[atomic, nuclear] In a NUCLEAR REACTOR, the neutrons are generally emitted within 10^{-14} s after the FISSION process with the incident NEUTRON. For ^{235}U , the half-life involving neutron DECAY ranges from 2.3×10^{-1} s to 56 s. During the fission process, other radioactive ELEMENTS are formed, some of which are neutron rich but these will decay with rates that are up to three orders of MAGNITUDE slower, referred to as the delayed neutrons. The delayed neutrons become an integral part of the reactor process control function when the reactor becomes “critical.”

Delta ray

[nuclear] A recoil PARTICLE that generates secondary IONIZATION produced during atomic interactions with ALPHA PARTICLES (helium ions). The term “delta ray” was introduced by JOSEPH JOHN THOMSON (1856–1940), in the early nineteen hundreds. Later, this term was refined to describe electrons that were released from an ATOM and have enough kinetic ENERGY to move away from the incident primary particle beam and subsequently ionize neighboring atoms. Additionally, in PARTICLE ACCELERATOR, the delta ray indicates electrons with significantly less kinetic energy, which will exhibit a spiraling DECAY process in a BUBBLE CHAMBER, decelerating at a characteristic rate.

Demodulator

[electronics, theoretical] An electronic device that extracts the encoded information from a CARRIER WAVE, demodulation. With respect to digital encoding, the demodulator is a software program (application process). One specific application of the demodulator is the PHASE-LOCKED LOOP and specifically RADIO (FM) tuning.

Dempster, Arthur Jeffrey (1886–1950)

[atomic, nuclear] A physicist from Canada. Arthur Dempster was an integral collaborator on the MANHATTAN PROJECT. In 1918, he developed the concept of the MASS SPECTROMETER and created a functional device. He also provided the theoretical foundation of MASS SPECTROSCOPY for today's applications (see [Figure D.24](#)).

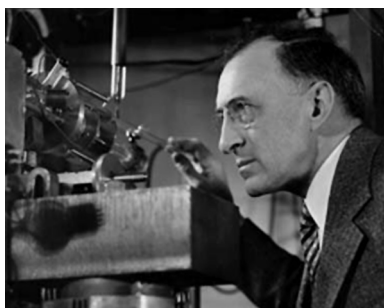


Figure D.24 Arthur Jeffrey Dempster (1886–1950). (Courtesy of Emilio Segrè Visual Archives c. 1925.)

Dempster's mass spectrograph

[atomic, nuclear] The first known MASS SPECTROMETER was designed by ARTHUR JEFFREY DEMPSTER (1886–1950) in 1918. The mass spectrometer separates particles a function of their mass and provides the scientific details to reconstruct the ISOTOPE configuration with respect to an element (see [Figure D.25](#)).

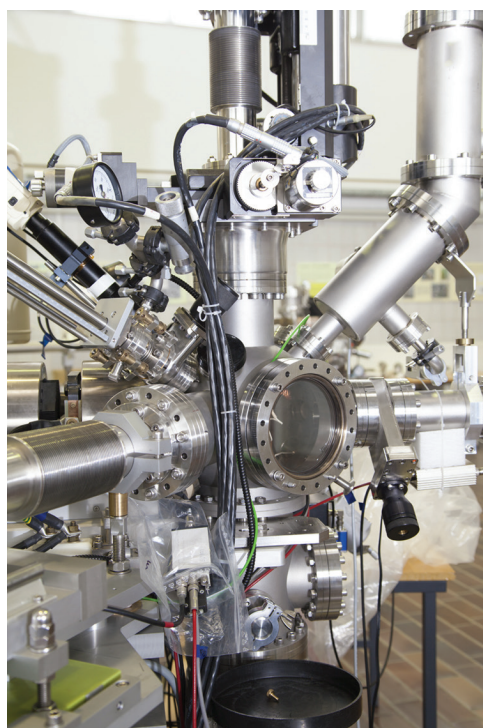


Figure D.25 Components of the Dempster mass spectrometer.

Density (ρ)

[general] Mass (m), respectively, charge ($Q = Ze$, $e = 1.60217657 \times 10^{-19}$ C the electron charge) per unit volume (V). Primarily, the mass density is $\rho = m/V$. Alternatively, the charge density is $\rho_e = Q/V$. In general, any parameter can be expressed as a density commodity, per unit volume.

Depletion layer

[electronics, general] In a semiconductor device construction, n -type and p -type materials are placed side by side with a transition layer forming in between to allow for a transition between the respective ENERGY levels of the two media. The depletion layer is virtually devoid of charge carriers, acting as an INSULATOR. The charge carriers are drawn to the p -type leaving the n -type side with holes (positively charged) due to the electrical potential difference generated by the close proximity placement forming a CAPACITOR across the depletion layer. Application of an external voltage will reduce the “width” of the depletion layer, inducing conduction as a function of the applied voltage, depending on the respective semiconductor materials: >300 mV for germanium and >650 mV for silicon. During reverse-bias situation, the electric field is in the opposite direction, broadening the depletion layer, attracting electrons in the n -type material to the positive pole and holes in the p -type material to the negative external pole.

Depolarization

[biomedical, chemical, electronics] A change with respect to electric equilibrium for a solid object or a cellular MEMBRANE. A polarized layer has an electrical discontinuity based on either differences in the concentrations of chemical constituents or electron displacement resulting from an applied electric field. A dry-cell BATTERY uses a depolarization layer to enhance the emf resulting from the buildup of ions formed in the generation of the emf. In biomedical applications, the depolarization is the process where the steady-state ionic differences between the intra- and extracellular LIQUID is disturbed under the influence of a chemical catalyst effect that changes the ION flow through specialized ports in the CELL MEMBRANE. The result is the formation of an ACTION POTENTIAL. The polarized state of the cell forms an electrical potential that obeys the NERNST EQUATION, where the depolarization process follows the process described by DAVID GOLDMAN (1910–1998), and in particular SIR ALLAN HODGKIN (1914–1998) and SIR ANDREW HUXLEY (1917–2012), the Hodgkin–Huxley equation.

Descartes, René (1596–1650)

[general, optics] A French scientist and mathematician. Descartes wrote a theoretical verification of the corpuscular properties of light in 1637: *La Dioptrique*, adopting the philosophies of the ancient Greek. With the corpuscular description, he was able to formulate a description of REFRACTION, and hence in France, the LAW OF REFRACTION (i.e., SNELL'S LAW) is often referred to as Descartes' law. He also formulated a thorough foundation of geometry in his book *Géométrie* in 1637. His influence in geometry includes the introduction of the mathematical notation of equations with known constants in an equation as the first letters of the alphabet: $a, b, c, \dots$, and the variables or values on the axis denoted with the last letters: x, y, z . This led to the formulation of the Cartesian coordinate system, named after Descartes. In his commitment to the newly adopted integral and differential formulation, he describes a cycloid with the equation $x^3 + y^3 = 3axy$, which is centered around the origin in this formulation, and has an enclosed segment with area $3/2 a^2$. Until SIR ISAAC NEWTON (1642–1727) introduced his gravitational theory, the scientific world was in favor of the VORTEX model of Descartes with regard to the planetary COHESION around the SUN, in this model the revolving Sun generates an AETHER vortex that pulls the planets in tow and holds them confined in “orbit.” In 1644, Descartes also postulated that the total amount of momentum in the GALAXY is constant and “can only be changed by god.” The statement by Descartes provided the basis of one of the first

CONSERVATION LAWS, followed by the CONSERVATION OF MASS law introduced by ANTOINE-LAURENT DE LAVOISIER (1743–1794) in 1789. This principle law of PHYSICS was followed in 1853 by the proclamation of the CONSERVATION OF ENERGY by WILLIAM JOHN MACQUORN RANKINE (1820–1872) (see [Figure D.26](#)).

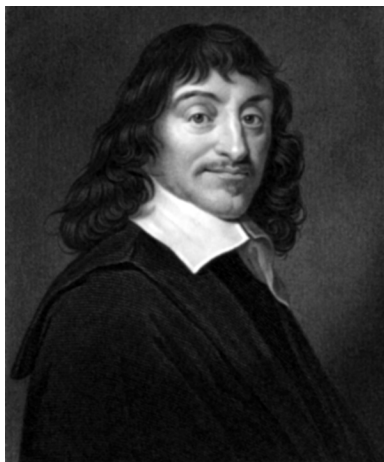


Figure D.26 René Descartes (1596–1650), engraved by W. Holl.

Deslandres, Henri Alexandre (1853–1948)

[astronomy, astrophysics, optics] A French astronomer and physicist, contemporary of GEORGE ELLERY HALE (1868–1938). Deslandres developed a spectral PHOTOGRAPHY mechanism (“spectroheliograph”) that allowed for spectral analysis of solar emissions as well as comets independent of the construction by Hale. In addition, his “spectro-enregistreur des vitesses” presumably allowed for time-resolved detection of chromospheric cloud emission (solar flares) that yielded the radial velocity of DRIFT of the flare (see [Figure D.27](#)).



Figure D.27 Henri Alexandre Deslandres (1853–1948). (Courtesy of Bulletin de la société astronomique de France, 1913.)

Deuterium (^2H)

[atom, nuclear] referred as “heavy hydrogen.” Symbol: D or $1\text{H}2$. The NUCLEUS of a deuterium ATOM contains 1 proton and 1 neutron. In atom count, deuterium accounts for approximately 0.0156 of all “hydrogen” and related isotopes in the earth’s water.

Deuteron

[atom, nuclear] NUCLEUS of deuterium, referred to as “heavy hydrogen.” Deuterium is an ISOTOPE of hydrogen: the nucleus of a deuterium ATOM contains 1 proton and 1 neutron. The other hydrogen isotope: protium (^1H) contains no NEUTRON in the nucleus and accounts for 99.98% of all hydrogen on the PLANET and is as known so far the most abundant ELEMENT in the UNIVERSE.

Deutsches Institut für Normung

[biomedical] Translation: German Institute of Standards, an organization responsible for standards in Germany and adopted by most of the world as DIN-standard (Deutsche Industry Norm). The equivalence is in the following standardization organizations: ISO (International Organization for Standardization), ANSI (developed by the American Society for Testing and Materials: ASTM), and IEEE (Institute of Electrical and Electronics Engineers), each providing standards on quality, communication, material choices, and safety (see [Figure D.28](#)).



Figure D.28 The DIN building in Berlin.

Dew

[geophysics, thermodynamics] Water VAPOR condensation, particularly observed in the morning. Dew forms from saturated AIR condensation on cooling surfaces, resulting from heat release to the ATMOSPHERE. Dew form on grass, plants, and objects, not on soil due to its respective conductive heating (see Figure D.29).



Figure D.29 Dew on spider web and brush.

Dew line

[thermodynamics] The thermodynamic description of a DISTILLATION process for a two-phase system (f , LIQUID and g , VAPOR), where the pressure per constituent, at temperature T , is defined as the fraction of the component (y_{if}) multiplied with the SATURATION pressure of that component ($P_{sat,i}$), under FLUID, and the remaining components with their respective contributions (Dalton pressure law) as $P = y_1 P_{sat,1f}(T) + \sum_{i=2}^n (1 - y_{if}) P_{sat,ii}(T)$, with P_{ii} the partial pressure of constituent i in unique SOLUTION. RAOULT'S LAW defines the gas-phase pressure ($P_{sat,ig}$) of constituent i in relation to the pressure as dissolved in liquid ($P_{sat,if}$) as $y_{ig} P = y_{if} P_{sat,ii}(T)$, and the CHEMICAL POTENTIAL (μ_{1f}) for constituent 1 in solution in reference to the unique substance μ_{11} is defined by $\mu_{1f} = \mu_{11}[T, P_{sat,11}(T)] + V_{11f}[P - P_{sat,11}(T)] + RT \ln y_{1f}$, where is the fluid volume for solution 1 and $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant. The fractional composition between liquid and vapor is linked through HENRY'S LAW as $y_{1g} P = y_{1f} \mathcal{H}_{1f}(T, P)$, where $\mathcal{H}_{1f}(T, P)$ represents the HENRY'S CONSTANT for SOLUTE 1 in liquid-phase solution. The full definition for the Henry constant is $\mathcal{H}_{1f}(T, P) = P_{sat,11}(T) \exp[(c_{1f}(T, P) - \mu_{11f}(T, P_{sat,11}(T)))/RT]$, where $c_{1f}(T, P)$ is a NORMALIZATION constant, and for an IDEAL SOLUTION $\mathcal{H}_{1f}(T, P) = P_{sat,11}(T)$. The dew line for constituent 1 in the distillation process for a two-component solution is now defined by $(1/P) = [y_{1g}/P_{sat,11}(T)] + [1 - y_{1g}/P_{sat,22}(T)]$, where now y_{1g} constitutes the solubility of liquid component 1 in gaseous SOLVENT constituent 2 and y_{2f} represents the solubility of gaseous component 2 in liquid solvent constituent 1. Note that the slope of the dew line changes with distillation concentration (compare the slope at $y_1 = 0$ to that at $y_1 = 1$). The dew line can be plotted in pressure versus fraction portion (P vs. y_1) or as temperature versus constituent portion (T vs. y_1).

Dew point

[thermodynamics] A temperature point where water VAPOR condenses to form LIQUID water. The temperature where the dew point is established is the DEW POINT TEMPERATURE.

Dew point temperature

[thermodynamics] The temperature where the water VAPOR has a partial pressure that has reached the SATURATION pressure and the water vapor will condensate and form LIQUID water.

Diamagnetism

[atomic, general, nuclear] The material repercussions in the magnetic orientation of an object caused by the internal EDDY CURRENTS in result of the application of an external MAGNETIC FIELD. Two kinds of orientation of the internal magnetic field can be recognized, parallel and anti-parallel. In case the internal magnetic field is in the opposing direction from the external filed, the magnetization is referred to as diamagnetic, whereas the congruent lineup of magnetic field lines is called PARAMAGNETISM. The object is hence diamagnetic or paramagnetic. This phenomenon is closely related to FERROMAGNETISM. Under diamagnetism, the external magnetic field is almost canceled in its entirety by the material's induced internal magnetic field. The magnetic permeability under diamagnetism hence has a value less than VACUUM (vacuum: $\mu_m^0 = 4\pi \times 10^{-7} Tm/A$), however slightly only. The magnetic behavior of diamagnetic materials is opposite to that of ferromagnetic materials or paramagnetic materials. The latter two are attracted to the MAGNETIC POLES, whereas the diamagnetic materials are repelled. Even though magnetization can be ferromagnetic or paramagnetic, virtually all materials have a tendency for diamagnetism, however in most cases understated. This phenomenon was first documented by MICHAEL FARADAY (1791–1867) in 1845. Faraday observed that certain materials (e.g., wood, GLASS, and gasses) exposed to a strong magnetic field are consistently repelled.

Diastolic pressure

[biomedical, general] Arterial pressure in mammals during the relaxed state of the HEART MUSCLE (fully distended heart muscle), in contrast to the SYSTOLIC PRESSURE. The systolic pressure constitutes the maximum pressure obtained at the peak of the contraction point by the heart muscle. The diastolic pressure is a function of the vascular COMPLIANCE and BERNOULLI'S LAW (see [Figure D.30](#)).

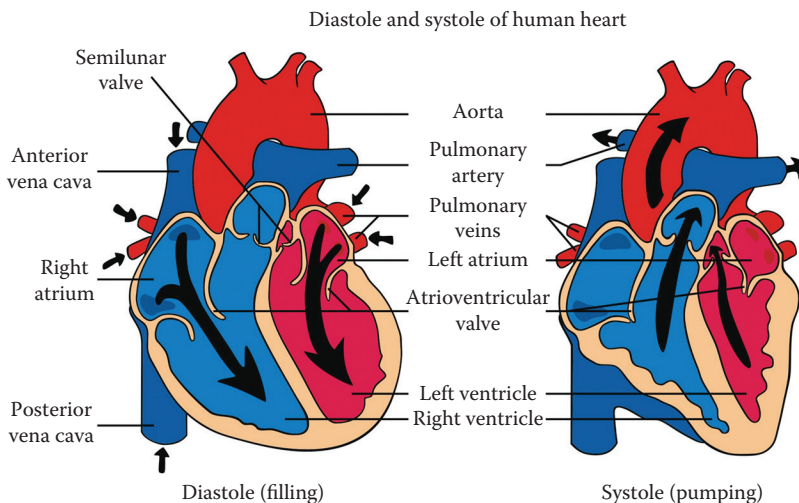


Figure D.30 Relaxed heart during diastolic pressure condition.

Diathermy

[general, thermodynamics] A method employed to add heat to the HUMAN BODY. One specific mechanism of action is the controlled application of high frequency current that is converted into heat locally and gradually (see [Figure D.31](#)).



Figure D.31 Woman receiving short-wave diathermy.

Dicrotic notch

[biomedical, fluid dynamics, mechanics, theoretical] A sharp rise and fall in ARTERIAL pressure directly behind the AORTIC VALVES in the AORTA immediately following SYSTOLE resulting from the relaxation of the VENTRICLE of the HEART during DIASTOLE, which causes the aortic valve LEAFLETS to close and in fact become pulled into the ventricle under the apparent relative VACUUM. The cupping of the aortic leaflets results briefly in a backflow from the aorta toward the ventricle, immediately followed by a cessation of FLOW, before the left ventricle prepares from systolic CONTRACTION and expulsion.

Diderot, Denis (1713–1784)

[general] A philosopher and scientist from France. Denis Diderot published a scientific encyclopedia (Encyclopédie) with JEAN LE ROND D'ALEMBERT (1717–1783). Denis Diderot expressed certain philosophies on the dimensions of space and time that were based on the work by FRANÇOIS-MARIE AROUET (also VOLTAIRE) (1694–1778) (see [Figure D.32](#)).



Figure D.32 Denis Diderot (1713–1784), painted by Louis-Michel van Loo in 1767.

Dielectric

[electromagnetism, general, thermodynamics] an equivalent for INSULATOR. Charges are refrained from moving freely. Under the influence of an external electric field, the dielectric medium will become polarized or made to retain a static charge. In contrast, a CONDUCTOR has free migration of charges, which provides for the phenomenon of current conduction. A conductor will not retain a static charge, even though an external electric field will separate the charges according to the electric field direction for the duration of the applied field. The conductor may remain charged if the free-moving electrons are siphoned off by toughing the polarized conductor with another conductor. Dielectrics are used in capacitors to maintain a charge separation between conducting plates. A material used to perform a specific electronic function with respect to shielding or insulation, dielectric material. A dielectric generally refers to a type of insulator, material with limited conductivity. The dielectric can be polarized to hold charge in most cases. A range of dielectric materials is used in the construction of capacitors to provide a specific value due to the relative dielectric constant ϵ of the medium, where the PARALLEL-PLATE CAPACITOR value (C) is defined as $C = \epsilon A/d$, where d is the plate spacing and A is the area of the capacitor plates. The documented specific conductivity of certain materials was first investigated with some rigor by the British amateur astronomer STEPHEN GRAY (1666–1736) in 1729.

Dielectric breakdown

[general] An electric field on the surface of a CONDUCTOR exceeding $\sim 3 \times 10^6$ V/m will break the electronic bond and results in IONIZATION of dry AIR, creating sparks. The static electric sparks resulting from rubbing polyester and NYLON mixtures together (e.g., socks on carpet) under dry air conditions can generate sparks under a static electrical potential in the order of $\sim 1 \times 10^4$ V. The electrical potential associated with an ELECTRIC CHARGE was described in detail by CHARLES DE COULOMB (1736–1806).

Dielectric constant (K_e)

[electronics, general, thermodynamics] The ratio of the DIELECTRIC permittivity of VACUUM (ϵ_0) to the dielectric permittivity of a medium (ϵ): $K_e = \epsilon/\epsilon_0$. The dielectric constant for water is $K_e = 80$, for Teflon $K_e = 2.1$, GLASS ranges from $K_e : 5 - 10$, and for NYLON $K_e = 3.5$ to name but a few.

Diesel cycle

[thermodynamics] A thermal cycle in ENERGY exchange, without the introduction of external energy to achieve an EXPANSION (resulting from combustion; the OTTO CYCLE, used to describe gasoline engines, requires a spark plug). The diesel cycle for a diesel ENGINE compresses the fossil fuel to a density/pressure that exceeds the ignition point, resulting in spontaneous combustion. The diesel cycle is comprised of the following four stages: (1) isobaric heating and expansion; (2) ISENTROPIC expansion; (3) isochoric cooling; and (4) isentropic compression. The diesel cycle can be executed by a reciprocating piston-cylinder engine. The work ($w_{\text{net}}^{\rightarrow}$) performed by the diesel engine, assuming a PERFECT GAS is defined by the heat produced per unit gas ($q_{12}^{\leftarrow}$, function of the “quality” of the fossil fuel) with respect to the respective temperature profiles in the various stages of the cycle (T_i) as $w_{\text{net}}^{\rightarrow} = q_{12}^{\leftarrow} \left\{ 1 - (1/\gamma_c) \left[(T_3/T_4) - 1 \right] T_4 / \left[(T_2/T_1) - 1 \right] T_1 \right\}$, where $\gamma_c = c_p/c_v$ is the ratio of the SPECIFIC HEAT under constant pressure over the specific heat at constant volume. The efficiency of the diesel cycle is the ratio of the work over the heat production $\gamma_{\text{eff}} = w_{\text{net}}^{\rightarrow}/q_{12}^{\leftarrow}$. The compression ratio (r_{comp}) is the relative VOLUME (V) change between stage 4 and stage 1, defined as $r_{\text{comp}} = V_4/V_1$, which ties the temperature difference between the two stages as $T_4/T_1 = r_{\text{comp}}^{-(\gamma_c-1)}$.

Dieterici, Conrad Heinrich (1858–1929)

[thermodynamics] A physicist from Germany (Prussian Empire). Conrad Dieterici focused his efforts on the explanation of thermodynamic processes, specifically the theoretical evaluation and definition describing specific circumstances (see [Figure D.33](#)).



Figure D.33 Conrad Heinrich Dieterici (1858–1929) c. 1907. (Courtesy of Universität Rostock, Rostock, Germany.)

Dieterici equation of state

[thermodynamics] Introduced as a correction to the VAN DER WAALS EQUATION, and actually more accurate, defined as $P(V - b_d) = RTe^{a_d/VRT}$, where $a_d = 4R^2T_c^2/e^2P_c$ is a factor describing the molecular interaction, $b_d = (1/2)V_c = (RT_c/e^2P_c)$ accounts for the molecular size of the Dieterici constant (different from the van der Waals constants), V_c is the critical volume, T_c is the CRITICAL TEMPERATURE, P_c is the critical pressure (all derived experimentally), $R = 8.3144621(75)$ J/Kmol is the universal gas constant, V represents volume, P represents pressure, T represents the temperature of the gas, with the number $e = 2.7182(8) = \sum_{n=0}^{\infty} (1/n!)$. Generally, the constants are listed in look-up tables for general use. The Dieterici equation of state was introduced by CONRAD HEINRICH DIETERICI (1858–1929) in 1899. The Van der Waals equations were introduced by JOHANNES VAN DER WAALS (1837–1923) in 1873.

Differential entropy

[imaging, theoretical] In IMAGE processing, specifically image registration, the comparison between pixels of image pairs can be classified under two categories: parametric and nonparametric. The point distribution of the image can be captured by the entropy outlining the PROBABILITY for the MEASUREMENT of the value μ_m with respect to the reference value v_m , defined under integral entropy $H_{f,v_m}(\mu_m) = -\int f(d\mu_m/dv_m)dv_m$, where f is a continuous function. Alternatively, the entropy of a random variable X can be defined by the probability of this value occurring in the data set ($p(x)$), given by the differential entropy or SHANNON ENTROPY $H_S(X) = -\int_{\Omega} p(x)\log(p(x))dx$. Under image registration, the data are compared against a standard with value Y , giving the joint (differential) entropy as outlining the entropy of finding similarities between X and Y , as the “conditional (differential) entropy” $H_S(X|Y) = -\int_{\Omega} p(x|y)\log(p(x|y))dxdy$ (also see SHANNON ENTROPY).

Diffraction, far field

[general, optics] DIVERGENCE and INTERFERENCE phenomena associated with the WAVE mechanisms due to edge phenomena. The redirection of mechanical waves due to obstructions was described by the Greek philosophers and for light by the Jesuit priest FRANCESCO GRIMALDI (1618–1663) from Italy in 1660. Furthermore, documented observations in 1723 by GIACOMO FILIPPO (JACQUES PHILIPPE) MARALDI (1665–1729) from Italy described the wave concept of light; however, this was not accepted by the scientific community. Without diffraction, an APERTURE or obstruction would project an IMAGE that has a uniform radiance across the entire imaging field, a single uniform bright spot from the aperture. In reality, the aperture generates a centralized bright spot with a less-bright (potentially totally void of RADIATION) minimum surrounding this central maximum, followed by additional, progressively less-bright maxima and intermitting minima in the radial direction of the imaging plane. The full-wave concept for light (ELECTROMAGNETIC RADIATION) was not fully verified until the experimental and theoretical work of THOMAS YOUNG (1773–1829) in 1801. Thomas Young illustrated the interference of waves from double slit with a single-LIGHT SOURCE. These observations were further validated by Agustin Fresnel (1788–1828) in 1818. In comparison, the basic principles of optical and mechanical REFRACTION at the interface of two media were defined through Snell law introduced by WILLEBRORD SNEL (SNELL) (WILLEBRORD SNEL VAN ROYEN [1591–1626]) in 1621 followed by the work on diffraction by AUGUSTIN JEAN FRESNEL (1788–1827). The “bending” of waves under the influence of the edge of an object in the path of electromagnetic radiation as well as mechanical waves (e.g., water waves) is described as refraction. When a WAVEFRONT with dimensions greater than the obstructions, greater than an opening (i.e., aperture), respectively, outer dimensions (e.g., the MOON between the SUN and the EARTH during a total eclipse), the wave aspect provides significant theoretical and practical implications. Under the Huygens–Fresnel principle (based on the work of CHRISTIAAN HUYGENS [1629–1695] and AUGUSTIN-JEAN FRESNEL [1788–1827]), each individual location in space in the path of a wave forms a secondary source emitting a SPHERICAL WAVE (depending on the geometry of the medium) in direction r . Hence, any wavefront is constructed of an infinite number of spherical waves, in particular for electromagnetic radiation. The secondary source has the same WAVELENGTH (λ , associated frequency $\nu = c/\lambda$, ANGULAR FREQUENCY $\omega = \nu 2\pi$, and c the speed of light) and PHASE as the primary source. The total wavefront is formed by means of superposition of all the secondary spherical wavefronts. In free space, the superposition provides a continuing PLANE WAVE. In case of an aperture, or LENS, the cross-sectional area is filled with secondary spherical sources. These individual sources are defined by the WAVE EQUATION with SOLUTION providing a MAGNITUDE as a function of DISTANCE as $E = (\xi_0/r) e^{i(kr - \omega t)}$, where ξ_0 is the generic source strength of each respective coherent source point and $k = 2\pi/\lambda$ is the wave number. The interference pattern from the infinitesimal sources in the aperture is observed at a distance $\vec{R}$ in the imaging plane. A detailed description of far-field diffraction was presented by JOSEPH VON FRAUNHOFER (1787–1826), that is, FRAUNHOFER DIFFRACTION. In imaging and general VISION, the ability to distinguish objects is the result of the diffraction limit. One application of interest is microscopy, where the investigation of the details is limited by the wavelength of the probing device (light, electron beam) as well as the design of the instrumentation used for delivery and collection of the ray of waves. Considering the collection of infinitesimal sources with radiance $\partial E = (\xi_a/r) e^{i(kr - \omega t)}$, emitted by infinitesimally small “surface areas” ds , located at distance $\vec{r}$ from the origin, assuming a centrally located reference frame. The “projection” from each source is defined by the vector $\vec{r} = \vec{R} - \vec{r}'$ with magnitude $r = \|\vec{r}\| = [(\vec{R} - \vec{r}') \cdot (\vec{R} - \vec{r}')] = \sqrt{(R^2 + r'^2 - 2\vec{R} \cdot \vec{r}')}$, providing $\partial E = [\xi_a/(R^2 - r'^2 - 2\vec{R} \cdot \vec{r}')^{1/2}] e^{i[k(R^2 + r'^2 - 2\vec{R} \cdot \vec{r}')^{1/2} - \omega t]}$. In the far-field case $\vec{R} \gg \vec{r}'$, allowing for a series approximation of $r_{\text{denominator}} = (1/R^2) \{1 - [(2\vec{R} \cdot \vec{r}' + r'^2)/R^2]\}^{1/2} = R \{1 + (1/2)[(2\vec{R} \cdot \vec{r}' + r'^2)/R^2]\} + (3/8)[(2\vec{R} \cdot \vec{r}' + r'^2)/R^2]^2 + \dots$, next to the exponential expression of the location: $r_{\text{exponent}} = R \{1 + [(r'^2 - 2\vec{R} \cdot \vec{r}')/R^2]\}^{1/2} = R \{1 + (1/2)[(r'^2 - 2\vec{R} \cdot \vec{r}')/R^2]\} + (3/8)[(r'^2 - 2\vec{R} \cdot \vec{r}')/R^2]^2 + \dots$. Truncating the binomial series $((r'^2/R) \rightarrow 0)$ after the first term, this yields $\partial E = (\xi_a/R) e^{i(kR - \omega t)} e^{i[k(\vec{R} \cdot \vec{r}')/R]}$. This term can be integrated over the area ds (total area: A) and can be expressed in Bessel function (J_1) as $E = (\xi_a/R) e^{i(kR - \omega t)} (2\pi/k r_i) R R_1 J_1(k r_i R_1/R)$, where r_i is the distance from the center point in the imaging plane and R_1 is the radius of the aperture. The intensity of the electric field is the complex conjugate multiplied by the regular function providing an expression that is known as the AIRY DISK. The central maximum is identified for $J_1(k r_i R_1/R) = 0$, which is valid for $(k r_i R_1/R) = 3.83$. From this, the radial distance to the first minimum is $r_i = 1.22 \lambda R / 2R_1$, which translates to the ABBE CONDITION for an image in the FOCAL POINT (f) of lens with diameter $D = 2R_1$, at

distance $R = f$: $\theta \cong \sin \theta = r_i/f = 1.22\lambda/D$, named after ERNST ABBE (1840–1905). Two maxima from two separate sources can hence be identified when one maximum falls in the minimum of the diffraction pattern from the other source. Alternatively, the RAYLEIGH CRITERION expresses this in a different manner, with respect to the NUMERICAL APERTURE of the lens $NA = n \sin \alpha$, giving the resolving power as $\text{RESOLVING POWER} = 0.61\lambda/NA$, where α represents half the acceptance ANGLE for the optical device (e.g., lens and fiber optic). A final remark is with respect to the binomial series for the far-field approximation; in the near-field approximation, the higher-order terms do conceal relevant information about the MICROSCOPIC features of the object being imaged. This latter becomes important in near-field scanning optical microscopy (NSOM) (see Figure D.34).



Figure D.34 Far-field diffraction, color pattern cast in the sky by the Sun diffracting from clouds.

Diffraction grating

[atomic, general, nuclear, optics] A series of parallel grooves on a surface of a transparent plate or a highly regular crystal structure used for WAVELENGTH (λ) analysis as well as material diagnostics. The diffraction grating can be considered a type of INTERFEROMETER. The first documented use of a diffraction GRATING was by JOSEPH VON FRAUNHOFER (1787–1826) in 1823. A diffraction grating with n slits, separated by DISTANCE d_{line} and width b (diffraction constant), produces a radiant intensity profile (i.e., radiance measured electronically: I) as a function of the ANGLE with the normal (θ) with the diffraction plate expressed as $I = I_0 (\sin n\alpha'/\sin \alpha') (\sin \beta'/\beta')$, where I_0 is the incident MAGNITUDE of radiance, $\alpha' = \pi d \sin \theta / \lambda$ and $\beta' = \pi b \sin \theta / \lambda$. The respective ($m = 0, 1, 2, \dots$) principal maxima will fall in the following directions: $d_{\text{line}} \sin \theta_m = m\lambda$ (i.e., GRATING EQUATION). For non normal incidence (at angle θ_i), this becomes $m\lambda = d_{\text{line}} (\sin \theta_i + \sin \theta_m)$.

Diffusion

[biomedical, chemical, computational, electronics, thermodynamics] The movement of small particles, in most cases the constituents in a SOLUTION. The diffusion process is driven by several factors; thermal agitation, potential gradient, and concentration gradient are the dominant factors. One specific example of electric-field-mediated diffusion is the transport of electrical current over a wire. Additionally, photons may also diffuse in a SCATTERING process, “gradually” making their ways in randomly distributed directions. Diffuse light emitted from a milky-WHITE LIGHT bulb, or frosted GLASS, involves the scattering process that randomly changes the propagation direction, classifying the PHOTON migration as diffusion. The process of facilitated (chemical) diffusion relies on external factor that provides “permission” for atoms and molecules

to pass through a BARRIER, such as a SEMIPERMEABLE MEMBRANE. In biological systems, the transport of chemical through the cellular membrane is mediated through LIGAND-gated channels, which assist in the selective passage of chemicals under the influence of a catalyst chemical in the proximity of the gated channel, thus activating the chemical mechanism of action for the transportation, or simply widening the ORIFICE supporting a higher transfer rate. One organ in particular is highly organized in the regulation of the diffusion, the KIDNEY. Ligand-gated membranes regulate processes such as (but not limited to) sleep/WAKE, pain, memory, and anxiety, which can be altered under the influence of chemical stimulants (legal and illegal drugs). In manufacturing, diffusion is applied to form crystal growth, next to marinating food for consumption as well as adding fungicides for preservation. Dialysis MACHINES use selective diffusion for the filtration process of BLOOD, replicating the functional processes of the KIDNEY. The diffusion process can be described by the DIFFUSION EQUATION, which has several forms. The most well-known DIFFUSION EQUATION is FICK'S LAW: $J = -D_{\text{chem}} (\partial[C]/\partial z)$, where $[C_i]$ is the concentration of SOLUTE i , with gradient in direction z , $D_{\text{chem}} = D_0 e^{-Q_{\text{ac}}/RT}$ is the diffusion coefficient (D_0 is a material constant, Q_{ac} is the activation enthalpy, $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant, and T is the temperature in KELVIN), and J is the particulate FLUX density, and as a function of TIME (t) provides Fick's SECOND LAW: $\partial[C]/\partial t = D_{\text{chem}} (\partial^2[C]/\partial z^2)$. Alternatively, Onsager's equation treats the process from THERMODYNAMICS principles: $J = -L_{\text{diff}} (\partial\mu_c/\partial z)$, where μ_c is the chemical potential and L_{diff} is the thermodynamic diffusion coefficient. Fick's first law can be expanded to include convection as $J = -D_{\text{chem}} (\partial[C]/\partial z) + [C]U_z$, where U_z is the convective migration velocity. For electrons, the diffusion is generally referenced as electron DRIFT with a current density J_e defined as $J_e = en\mu_e E + eD_e (dn/dz)$, where $e = 1.60217657 \times 10^{-19} \text{ C}$ is the electron charge, n is the number of electrons/"holes" per volume (charge density), μ_e is the electron mobility (material property), and $D_e = \mu_e v_t = \mu_e (k_b T/e)$ is the electron diffusion coefficient ($v_t = k_b T/e$ is the Einstein's relationship for electrical mobility and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ is the Boltzmann constant). The total transport of particles in the diffusion process was introduced by Stefan Boltzmann in 1872 as a PROBABILITY function, using a functional correlation between the velocity of a PARTICLE (finite range of MAGNITUDE and direction) and its respective location as a function (with uncertainty) of time next to the net result of loss and gain from a unit volume as the TRANSPORT EQUATION. The statistically anticipated number of particles with velocity v with bandwidth dv in location r with spread dr is given for constituent i at time t as $f_i(\vec{r}, \vec{v}_i, t)$, which is linked in transport to the interparticle collision, defined by the collision CROSS SECTION σ_{ij} and the respective Coulomb interaction $g_{ij}(r)$ to yield the loss and gain balance for a volume of space (Ω), summarized over all components: $\sum_{j=1}^n \iiint (f'_i(\vec{r}, \vec{v}_i, t) f'_j(\vec{r}, \vec{v}_j, t) - f_i(\vec{r}, \vec{v}_i, t) f_j(\vec{r}, \vec{v}_j, t)) \sigma_{ij} g_{ij}(\vec{r}) (g_{ij}(\vec{r}), \vec{r}) d\vec{v}_i d\vec{v}_j d\Omega$. The net transport need to match the diffusion for six DEGREES OF FREEDOM with respect to the N number of particles, and resulting $6N$ first-order differential equations, which is generally contracted to an equivalent single-particle distribution following: $(\partial f_i(\vec{r}, \vec{v}_i, t)/\partial t) + \vec{v}_i \cdot (\partial f_i(\vec{r}, \vec{v}_i, t)/\partial \vec{r}) + \vec{D} \cdot (\partial f_i(\vec{r}, \vec{v}_i, t)/\partial \vec{v}_i) = \sum_{j=1}^n \iiint (f'_i(\vec{r}, \vec{v}_i, t) f'_j(\vec{r}, \vec{v}_j, t) - f_i(\vec{r}, \vec{v}_i, t) f_j(\vec{r}, \vec{v}_j, t)) \sigma_{ij} g_{ij}(\vec{r}) (g_{ij}(\vec{r}), \vec{r}) d\vec{v}_i d\vec{v}_j d\Omega + S(\vec{r}, \vec{v}_i, t)$, where $S(\vec{r}, \vec{v}_i, t)$ is a particle source, which may be IONIZATION (electron/hole diffusion) or a chemical reaction or a reactive DECAY process; the source may be absent for general diffusion processes. An equivalent description is applied to photon transport described under the radiative transport equation (also the equation of radiative transport).

One elementary example is the process of infusing food with special flavors while marinating, or the natural preservation of food by submersion in vinegar or other solution (see [Figure D.35](#)).



Figure D.35 Marinating peppers.

Diffusion equation

[biomedical, chemical, computational] A description of the migration of particles, specifically small molecules across a BARRIER that can be either chemical, mechanical, or electrical (POTENTIAL BARRIER), also known as FICK'S EQUATION. DIFFUSION is associated with the transport of gases (e.g., O_2 , CO_2 , and NO), as well as small molecules, and molecules soluble in polar solvents migrating through the CELL MEMBRANE. The diffusion process is driven by concentration gradients and will continue until an equilibrium is reached, both based on OSMOTIC PRESSURE as well as on chemical concentration ($[Chem]$). The diffusion rate (J_{Chem}) is directly proportional to the cross-sectional area (A) of the partition (e.g., MEMBRANE), the concentration gradient $\Delta[Chem]$, the diffusion coefficient for the chemical substance in question (D_{Chem}), and inversely proportional to the DISTANCE (Δx) over which the chemical needs to traverse $J_{Chem} = -D_{Chem} A (\Delta[Chem] / \Delta x)$, known as Fick's law. The associated diffusion time is a function of the diffusion distance and the diffusion coefficient, also in reference to the permeability coefficient (based on the Einstein relation) $t_{diff} = (\Delta x)^2 / 2D_{Chem}$. The diffusion coefficient for small molecules is inversely proportional to the MOLECULAR WEIGHT (in Dalton). For large "spherical" molecules, the diffusion coefficient can be derived from the Stokes–Einstein relationship, based on the radius of the dissolved molecule ($r_{molecule}$) and yields $D_{Chem} = RT / 6N_a \pi r_{molecule} \eta$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the GAS constant, T is the temperature, η is the VISCOSITY of the LIQUID, and $N_a = 6.022137 \times 10^{23} \text{ J/K}$ is Avogadro's number. The molecular radius is the effective Stokes radius, expressed as $r_{solute} = (3MW / 4\pi \rho N_a)$, where ρ is the SOLUTE density and MW is the molecular weight in Daltons ("dimensionless"; 1/12 the mass of one single ^{12}C ATOM).

Diffusion length

[atomic, chemical, electronics, fluid dynamics, nuclear] In electronic design, the diffusion length applies to semiconductor design, specifically p - n and np junctions. The diffusion length for SEMICONDUCTORS relates the average DISTANCE traveled by electrons to initiate recombination. The recombination process is the lifetime of the charge CARRIER and the materials used in the formation of the semiconductor, the number of defects created in the materials as well as the DOPING medium. In heavily doped silicon, the Auger recombination

will be the prevailing process in recombination. The diffusion length (L_{diff}) for the semiconductor is defined as the square root of the product of the lifetime (τ_{recom}) and the DIFFUSIVITY (D_{diff}): $L_{\text{diff},e} = \sqrt{D_{\text{diff}} \tau_{\text{recom}}}$, where the lifetime can be as long as 1 ms, and the diffusivity (equivalent to diffusion coefficient) is the electron diffusion coefficient $D_{\text{diff},e} = \mu_e (k_B T / e)$ ($k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ is the Boltzmann constant, $e = 1.60217657 \times 10^{-19} \text{ C}$ is the electron charge, μ_e is the electron mobility [material property]). For the hole diffusion coefficient: $D_{\text{diff},h} = \mu_h (k_B T / e)$ (μ_h the hole mobility [material property]). For solar cells, the typical diffusion length is in the order of 100–300 μm . In chemical diffusion, the diffusion length is the square root of the product of the diffusion coefficient (D_{chem}) and the diffusion process timeframe (t): $L_{\text{diff,chem}} = \sqrt{D_{\text{chem}} t} = 2\sqrt{\int_0^t D_{\text{chem}}(t') dt'}$.

Diffusion-limited aggregation

[chemical, computational] A reactant process limited in its MAGNITUDE by the DIFFUSION process. Next to diffusion, transport can take place based on convection or chemical reaction itself, also known as diffusion limited process (*also see* DAMKÖHLER NUMBER).

Diffusivity

[biomedical, chemical, fluid dynamics, general, mechanics] For electromagnetic induction on fluids, the FLUID motion is a factor that needs to be taken into account for the influences of ELECTROMAGNETIC RADIATION on the FLOW patterns of conducting fluids. This mechanism of action falls under MAGNETOHYDRODYNAMICS. The interaction time for the MAGNETIC FIELD with the fluid is captured by the electromagnetic DIFFUSION time: $\tau_\eta = L_{\text{EM}}^2 / \eta_m$, where L_{EM} is the characteristic electromagnetic DIFFUSION LENGTH (which can potentially be excessively long, specifically when considering stars, this may exceed the lifetime of the STAR). The magnetic diffusivity is defined as $\eta_m = 1 / \mu_e \sigma_e$, where $\mu_e = \mu_r \mu_{e0}$ is the permeability of the medium, $\mu_{e0} = 4\pi \times 10^{-7} \text{ H/m}$ is the permeability of VACUUM, $\sigma_e = 1 / \rho_e$ ($\rho_e = R(A/\ell)$ is the resistivity, R is the RESISTANCE, A is the cross-sectional area of charge flow, and ℓ is the characteristic length) is the electrical conductivity. The fluid can be a watery mix, but also may be PLASMA or magma. With respect to the magnetic induction, the MAGNETIC REYNOLDS NUMBER can be introduced $Re_m = v L_{\text{EM}} / \eta_m$, where v is the fluid VELOCITY (*also see* ALFVÉN THEOREM).

Diffusivity constant

[biomedical] The scale of migration of SOLUTE a through SOLVENT b: $D_{ab}(T, \eta)$ (function of the solvent's chemical and material properties, TEMPERATURE T , and VISCOSITY η), as applicable to Fick's first law (*also see* DIFFUSION COEFFICIENT).

Dilatant fluids

[biomedical, fluid dynamics] SHEAR-THICKENING FLUID, fluid that increases in SHEAR FORCE with increasing FLOW velocity. The associated viscous phenomena also increase with a rise in VISCOSITY per se, in contrast with a NEWTONIAN FLUID or PSEUDOPLAST FLUID.

Dilation of time

[atomic, quantum] Considering two independent systems (system 1 and 2, respectively, denoted by the primary subscript) traveling with respect to each other while two sequential events takes place within one of the system that is observed in both systems. Under classical MECHANICS, the transfer of information would take place at phenomenal velocity, making the observation unquestionably simultaneous for both systems.

However, under the acceptance that the speed of light is the fastest known velocity for communication of data, the **SIMULTANEITY** between the two systems becomes questionable when either or both system travel at velocities approaching the speed of light, in particular that both systems are moving with respect to each other at relative velocity v_r . In case the two systems are traveling on the same axis, the concept of dilation of time can easily be illustrated by using the respective origins as the reference points. As two sequential events occur in system one (1), respectively, at location $x_{1,1}$ at time $t_{1,1}$ followed by the second event at location $x_{1,2}$ at time $t_{1,2}$, the Lorentz–Einstein relativistic time transformation yields for the two observers traveling in the two separate systems: location $x_{2,1} = \{1/\sqrt{1-(v_r^2/c^2)}\}(x - v_r t)$ ($c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s is the speed of light in **VACUUM**), while the time transformation yields $t_{2,1} = \{1/\sqrt{1-(v_r^2/c^2)}\}[t_{1,1} - (v_r x_{1,1}/c^2)]$ and $t_{2,2} = \{1/\sqrt{1-(v_r^2/c^2)}\}[t_{1,2} - (v_r x_{1,2}/c^2)]$, respectively, signifying that there is a difference between the time observed in reference frame 2 with respect to reference frame 1, expressed as $t_{2,2} - t_{2,1} = \{1/\sqrt{1-(v_r^2/c^2)}\}[(t_{1,2} - t_{1,1}) - (v_r/c^2)(x_{1,2} - x_{1,1})]$. Setting the frame 1 as the standard, reflecting “proper time” (local time), and syncing both events, the time difference between the two system is now $(t_{2,2} - t_{2,1}) = \{1/\sqrt{1-(v_r^2/c^2)}\}(t_{1,2} - t_{1,1})$, which also applies vice versa and validates simultaneity between the two systems. However, when the two events in system 1 do not occur at the same location ($x_{1,1} \neq x_{1,2}$), the two events can be observed in system two in three different situations: (1) the sum in the square brackets can still yield zero in which case the events are still observed simultaneously in system 2; (2) the sum yields a positive value while $t_{1,2} > t_{1,1}$ the events are observed in the same order in system 2; and (3) the sum in the square brackets yields a negative value while still $t_{1,2} > t_{1,1}$ the events are observed in the reverse order in system 2. This can be observed theoretically after a rewrite: $t_{2,2} - t_{2,1} = \{(t_{1,2} - t_{1,1})/\sqrt{1-(v_r^2/c^2)}\}\{1 - (v_r/c)[(x_{1,2} - x_{1,1})/c(t_{1,2} - t_{1,1})]\}$, illustrating condition “3” occurs only when $[(x_{1,2} - x_{1,1})/c(t_{1,2} - t_{1,1})] > (c/v_r)$. This type of inequality will only be realized when the **DISTANCE** between the location of the two events ($x_{1,2} - x_{1,1}$) spans a greater distance than the distance traversed by the light within the time frame $(t_{1,2} - t_{1,1})$. Keep in mind that in case the spatial separation would be large enough for the latter reversal to occur the light leaving event 1 could never reach event 2 prior to its manifestation (III). This condition rules out that a causal sequence of event can never be reversed, even observed in system 2. One notable consequence of time dilation is often referenced as the twin paradox (*also* **TIME DILATION** and **LENGTH CONTRACTION**) (see [Figure D.36](#)).

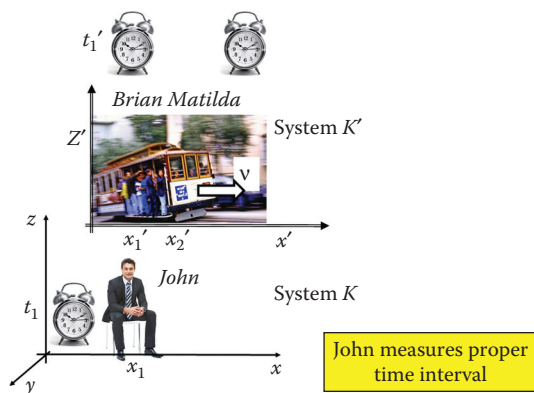


Figure D.36 Dilation of time for a reference-frame moving with respect to a stationary reference frame.

Dilution law of Ostwald

[atomic, biomedical, chemical, general, quantum] Correlation between the dissociation constant $K_d = \{[C^1]^a \times [C^2]^b\} / [C^1 C^2]$ for a chemical reaction $(C^1)_a (C^2)_b \rightleftharpoons aC^1 + bC^2$, with chemicals C^1 and C^2 in concentrations $[C^1]$ and $[C^2]$, respectively) to the degree of dissociation with respect to a weak electrolytic **SOLUTION**.

The dissociation is the process of ionic compounds splitting in their constituents (e.g., salts). The degree of dissociation is defined as the fraction of original molecules that have split-off in their ionic components. The degree of dissociation is linked to the VAN'T HOFF FACTOR (i_H) for a SOLUTE with a maximum of n potential ions as $i_H = 1 + \alpha_d(n-1)$. The dilution law of Ostwald is now $K_d = (\alpha_d^2/1 - \alpha_d)[C^e_0]$, where $[C^e_0]$ is the original concentration of ELECTROLYTE. This was introduced by the chemist FRIEDRICH WILHELM OSTWALD (1853–1932) (from what is now known as Latvia) in 1902. The IONIZATION constant in the ARRHENIUS EQUATION for ELECTROLYTIC DISSOCIATION is independent of the concentration of electrolytes. The Ostwald law will also apply to the various stages of QUANTUM dot formation (also referred to as “ripening”) and dissociation.

Dimensionless numbers

[computational, general] There are numerous scaling parameters that are used as either calibration factors or as an indication of which computational regiment a specific phenomenon is grouped under, such as turbulent versus LAMINAR FLOW. The following dimensionless numbers are identified, please check the respective entries for a full explanation: ALFVÉN NUMBER ($A_L = cv_{\text{fluid}}/v_d$); ARCHIMEDES NUMBER ($Ar = g\rho L^3/\mu^2$); ARRHENIUS NUMBER ($\alpha^* = E_0/RT$); Bernoulli number ($x/(e^x - 1) = \sum_{n=0}^{\infty} B_n x^n/n$); Bernoulli number of the second kind ($b_n = \int_0^1 (x^n) dx$); BINGHAM NUMBER ($Bm = \tau_y L/\eta v$); BIOT NUMBER ($Bi = hL/k$); BIOT NUMBER, MASS TRANSFER ($Bi_m = h_m L/D_{AB}$); BLAKE NUMBER ($Bl = v\rho/\eta(1 - \varepsilon)A_i$); BODENSTEIN NUMBER ($Bs = vL/D_{v,d}$); BOND NUMBER ($Bo = [g(\rho_\ell - \rho_v)L^2]/\gamma_s$); BRINKMAN NUMBER ($Br = \eta v^2/\kappa_{\text{cond}}(T - T_0)$); Brinkman number, modified ($Br^* = (T - T_0)_{\text{iso}}/(T - T_0)$); CAPILLARY NUMBER ($Ca = \eta v/\gamma_s$); CAUCHY NUMBER ($C = \rho v^2/E$); CAVITATION NUMBER ($\sigma_c = 2(P - P_v)/\rho v^2$); COEFFICIENT OF FRICTION ($C_f = \tau/(1/2)\rho v^2$); Colburn j-factor, heat transport ($j_H = StPr^{2/3}$); Colburn j-factor, mass transport ($j_m = St_m Sc^{2/3}$); CONDENSATION NUMBER ($Co = g\rho^2 \Delta H_{\text{vap}} L^3/k\eta \Delta T$); DEAN NUMBER ($Dn = Re \times \sqrt{(D/2R)}$); DEBORAH NUMBER ($De = t_f |\bar{v}|/L$); DRAG COEFFICIENT ($C_d = g(\rho - \rho_f)L/\rho v^2$); drag coefficient ($C_D = F_D/[(1/2)\rho v^2](\pi R^2)$); Eckert number ($Ec = v^2/c_p(T_i - T_\infty)$); ELASTICITY NUMBER ($El = \theta_r \eta/\rho R^2$); Eötvös number ($Eu = (\rho - \rho_f)L^2/\sigma_{\text{surf}}$); EULER NUMBER ($Eu = \Delta P/\rho v^2$); Euler number ($(\cosh t)^{-1} = 2/(e^t + e^{-t}) = \sum_{n=0}^{\infty} (E_n/n!) \times t$); FINE-STRUCTURE CONSTANT ($\alpha_{\text{fine}} = e^2/4\pi\hbar c$); FLUIDIZATION NUMBER ($N = \rho s 3d 4g 2/\mu f 2 E M$) [<http://www.scribd.com/doc/88982439/Fluidization-Gupta>, p20], FOURIER NUMBER ($Fo = \kappa t/c\rho L^2$); FOURIER NUMBER, MASS TRANSFER ($Fo_m = D_{AB}t/L^2$); FRESNEL NUMBER ($N_F = a^2/\lambda z$); FRICTION FACTOR ($f = \Delta P/(L/D)[(1/2)\rho v^2]$); FROUDE NUMBER ($Fr = v^2/gL$); GALILEO NUMBER ($Ga = gD^3\rho^2/\eta_{\text{kin}}^2$); GRASHOF NUMBER ($Gr = g\beta\rho^2(T_i - T_\infty)L^3/\eta_{\text{kin}}^2$); GRASHOF NUMBER, MASS TRANSFER ($Gr_m = (1/\rho)(\partial\rho/\partial[a])_{T,p} g([a]_i - [a]_d)L^3/\eta_{\text{kin}}^2$); GRÄTZ NUMBER ($Gz = \dot{m}c_p/kL$); HODGSON NUMBER ($H = fV\Delta P/Q\bar{P}$); JAKOB NUMBER ($Ja = c_p(T_i - T_{\text{sat}})/\Delta H_{\text{vap}}$); KNUDSEN NUMBER ($Kn = \lambda/L$); LEWIS NUMBER ($Le = \kappa/D_{AB}$); LOCKHART–MARTINELLI NUMBER ($\chi = \dot{m}_\ell/\dot{m}_g\sqrt{\rho_g/\rho_\ell}$); Lorentz number ($L_{t-e} = \kappa_{\text{cond}}/\sigma_e T = \pi^2 \kappa_{\text{cond}}^2/3e^2$); LUNDQUIST NUMBER ($Lu = v_d L/\eta$); MACH NUMBER ($Ma = v/v_{\text{sonic}} = \sqrt{Re \times Wi}$); MIXING TIME ($\theta_m = t_m/t_c$); MORTON NUMBER ($Mo_{\text{Liquid}} = g\eta_f^4 \Delta\rho/\rho_f^2 \sigma^3$); Newton number ($Ne = F_{\text{drag}}/\rho_f v^2 \ell^2$); NUSSELT NUMBER ($Nu = h_f L/\kappa$); OHNESORGE NUMBER ($Z = \eta/\sqrt{\rho L \sigma}$); PÉCLET NUMBER ($Pe = vL/\alpha$); Péclet number, mass transfer ($Pe_m = vL/D_{\text{dif}}$); PIPELINE PARAMETER ($\rho'' = v_{\text{gr}} v_0/2gH$); POISEUILLE NUMBER ($Ps = v_{\text{ph}} \eta/gd_p^2(\rho_s - \rho_f)$); POWER NUMBER ($N_p = c_{Np}(P_w/\omega_N^3 \rho L^5)$); PRANDTL NUMBER ($Pr = \nu/\alpha$); PRESSURE COEFFICIENT ($Pt = (P - P_\infty)/(1/2)\rho_\infty v_\infty^2$); RAYLEIGH NUMBER ($Ra = L^3 \rho^2 g \alpha_{\text{exp}} \Delta T c_p/\eta \kappa = GrPr$); REYNOLDS NUMBER ($Re = vL\rho/\eta$); REYNOLDS NUMBER, MAGNETIC ($Re_m = \mu \sigma v_n L$); SABERIAN NUMBER ($Sa =$); SCHMIDT NUMBER ($Sc = \eta/\rho D_{AB}$); SHERWOOD NUMBER ($Sh = h_m L/D_{AB}$); STANTON NUMBER ($St = h/\rho v c_p = Nu_L/Re_L Pr$); Stanton number, mass transfer ($St_m = h_m/\rho v = Sh_L/Re_L Sc$); STROUHAL NUMBER ($Sr = v_n L/\nu$); WALL-FACTOR 1 ($K_2 = 2(d_{\text{PV}}/D_C)$); WALL-FACTOR 2 ($K_3 = (d_{\text{PV}}/D_C)(Z/D_C)$); WEBER NUMBER ($We = \text{Const}(\rho v^2 L/\sigma)$); Wiedermann–Franz ratio ($L_{t-e} = (\kappa_{\text{cond}}/\sigma_e T) = \pi^2 \kappa_{\text{cond}}^2/3e^2$); Weissenberg number ($Wi = t_f |\bar{v}|/D$); WOMERSLEY NUMBER ($\alpha_{W_o} = r\sqrt{\rho\omega/\eta}$).

Diode

[electronics, general] A VACUUM-tube configuration (inception: Thomas Alva Edison [1847–1931] 1883) in its primary form as well as semiconductor with a single charge BARRIER constructed with charge DOPING of silicon or germanium LATTICE structures. A junction with on one side a medium that is doped with acceptors and produces “positive charges” (i.e., holes), the p -type material, mated with a NEGATIVE CHARGE emitter doping (donor type; n -type), separated by a DEPLETION LAYER is referred to a p - n junction. The characteristic electronic property of the diode is that it will only allow current to transfer in one direction (for the p - n junction, from p -type side to n -type side) (*also see* SEMICONDUCTOR, P-N JUNCTION, and N-P JUNCTION) (see [Figure D.37](#)).



Figure D.37 Picture of representative diodes.

Diode laser

[general, optics, quantum, solid-state] Light amplification by STIMULATED EMISSION of RADIATION with respect to the use of a DIODE LIGHT SOURCE. The p - n junction offers a highly effective means for ELECTROLUMINESCENCE, initially used to produce LED's (light-emitting diodes), introduced in 1962 by General Electric® led by ROBERT N. HALL (1919–). The discovery of electroluminescence dates back to Henry JOSEPH ROUND (1881–1966) at the Marconi Laboratories in 1907. The choice of materials used for the p - n junction sets the scale for the emitted wavelength base on the PHOTOELECTRIC EFFECT $\nu = E/h$, where $\nu = \lambda/c$ is the frequency, λ is the wavelength, $c = 2.9979245(8) \times 10^8$ m/s is the speed of light, E is the ENERGY in reference to the work function (ϕ_p ; $h\nu = KE - \phi_p$, KE is the additional kinetic energy of the electron in the VALENCE BAND) of the material and $h = 6.62606957 \times 10^{-34}$ m²kg/s is the Planck's constant. The combination of the work function of a material and the maximum kinetic energy will provide the EMISSION SPECTRUM limits of the diode. Placing the LED material inside a cavity constructed of two opposing mirrors can under specific conditions create the platform for laser excitation and laser emission. Specific configurations of diode laser are horizontal emitting laser (HCSEL: horizontal cavity, surface-emitting laser) and vertical emitting diode (VECSEL: vertical-external-cavity surface-emitting laser). Over the years, the emission wavelength has gradually diminished, reaching into the ultraviolet-C (UV-C) ($\lambda \sim 260$ nm) currently, while during its introduction only INFRARED emission (~ 870 nm) was possible. Ever since then the upper and lower limits are continuously challenged,

reaching in the mid-infra-red 3330 nm, GaInAsSb. The significant advantage of diode laser is their potentially small size (see [Figure D.38](#)).



Figure D.38 Picture of a diode laser, this one in particular operates at 830 nm.

Diopeters (D)

[general, optics] The power of a LENS, captured as the reciprocal value of the focal length. Due to its definitions, the lens power in diopters is additive. For VISION correction, a far-sighted person needs to gain close DISTANCE vision by means of a lens system with a positive value, whereas near-sightedness can be corrected by a negative diopter lens. A positive diopter lens is a magnifier, whereas a negative diopter will result in a virtual IMAGE.

Dipole

[atomic, biomedical, chemical, condensed matter, electromagnetism, electronics, general, solid-state] A charge configuration that results in a respective positive and negative net-charge concentration in three-dimensional space of equal MAGNITUDE that is separated by a fixed or variable DISTANCE. Certain animals produce a DIPOLE FIELD to aid in orientation of movement and target location for hunting. Examples of dipole-equipped animals are the Platypus and the elephantnose fish *Gnathonemus* (African freshwater fish). A dipole pruces a well-organized electric field configuration. RADIO waves emitted from an ANTENNA use the antenna as the dipole in which the magnitude of the respective charge fluctuates over time with the driving modulation frequency, either in AMPLITUDE (magnitude of SIGNAL strength, meaning magnitude of charge; i.e., A.M. modulation) or in OSCILLATION frequency (high-frequency CARRIER WAVE [kHz or predominantly Mhz] with super-imposed modulation, usually in the audible frequency range) (see [Figure D.39](#)).

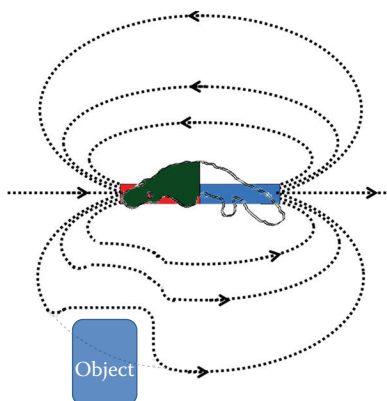


Figure D.39 Platypus as an electric dipole.

This phenomenon applies both to ELECTRIC CHARGES and MAGNETIC FIELD. In electric charge distribution, an object that has a cluster of POSITIVE CHARGE separated forms an equal amount of NEGATIVE CHARGE, where the virtual charge centers are at a distance that can be determined. An oscillating variable distance produces an antenna, emitting ELECTROMAGNETIC RADIATION. The electric field lines created by the ELECTRIC DIPOLE are very uniform and form a perfect mirror IMAGE from the positive to the negative pole with respect to the central plane between the charge centers. Due to the split positive and negative charge, the dipole creates a dipole moment. A MAGNET that by definition has a NORTH and south pole is a MAGNETIC DIPOLE, specifically since the single object will by definition have equal field lines coming in as there are emanating, essentially due to the fact that magnetic field lines are closed (*see GAUSS'S LAW*).

Dipole field

[electromagnetism, general] The electric field lines connecting the positive and negative charges of a DIPOLE. Due to the equal MAGNITUDE of the net charges of a dipole, the electric field configuration on a MACROSCOPIC scale is highly uniform and symmetric.

Dipole layer

[biomedical, chemical, electronics, general, solid-state] A layer that has two opposite sign charges on either side. The DIPOLE moment for a point charge distribution with MAGNITUDE q (equal magnitude but opposite charges) is $p_{\text{dipole}} = q\delta$. The electrical potential (V_p) resulting from a dipole charge distribution in point P at great DISTANCE from the dipole ($r \gg \delta$; r the distance from the center of the dipole to the point P, δ the dipole distance) is defined as $V_p = K \left(\frac{p_{\text{dipole}} \cdot \vec{r}}{r^3} \right) = K \left(\frac{p_{\text{dipole}} \cos \theta}{r^2} \right)$, where θ represents the ANGLE with the normal to the axis of the dipole and K represents a constant. Replacing the POINT CHARGES with layers of equal charge results in reconfiguring the dipole moment in a dipole moment per surface area (A): $m = q\delta/A = \sigma_{\text{charge}}\delta$, now δ is the plate separation. In this situation, the electrical potential at a distant point P is defined as a function of location with respect to the entire plate with charges, in reference to the central location on the plate, as $dV_p = K \left(\frac{m_{\text{dipole}} \cdot d\vec{A}}{r^3} \right) = K \left(\frac{m_{\text{dipole}} \cos \theta dA}{r^2} \right) = Km_{\text{dipole}} d\Omega$, where Ω is the SOLID ANGLE. Considering the entire surface contribution yields for the potential $V_p = \int_{\text{surface-angle}} Km_{\text{dipole}} d\Omega = Km_{\text{dipole}} \Omega$, point P observes the entire surface with the solid angle Ω .

Dipole moment (p_{dipole})

[chemical, condensed matter, electronics, general, solid-state] Generally referring to an ELECTRIC DIPOLE, the dipole associate with a MAGNETIC FIELD distribution is generally specifically named the "MAGNETIC DIPOLE" with a "magnetic moment." The charge "pivot" (two equal but opposite charges [q^+ ; q^-] separated by a DISTANCE d) expressed at a distance $\vec{r}$ is defined as $p_{\text{dipole}} = q\vec{r}$. POLARIZATION is a special case of dipole moment, signifying the ELECTRIC DIPOLE MOMENT per unit volume. Placing a dipole in an external electric field ($\vec{E}$) will generate a torque with MAGNITUDE and the direction perpendicular to the field $\vec{\tau}_E = \vec{E} \times \vec{p}_{\text{dipole}}$. Note, compare this to the torque from a magnetic field ($\vec{B}$) on the magnetic moment $\vec{\tau}_B = \vec{B} \times \vec{\mu}_B$, where the magnetic moment is defined as $\vec{\mu}_B = \vec{m}_B = (1/2)q\vec{r} \times \vec{v}$ for an ELECTRIC CHARGE moving in a circle with radius r at velocity v (creating a current), or expressed with respect to a current loop (I) with vector field area $\vec{A}_S$: $\vec{\mu}_B = I\vec{A}_S$. POLARIZATION (P_{pol}) in this case refers to the average dipole moment of a group of N elementary dipoles (atomic or molecular) defined as $P_{\text{pol}} = N \left(p_{\text{dipole}} \right) = N\alpha_{\text{pol}}E = \chi(E/4\pi)$, where E is the electric field

strength, α_{pol} is a material property referred to as the polarizability, and χ is the susceptibility of the electric system (see Figure D.40).

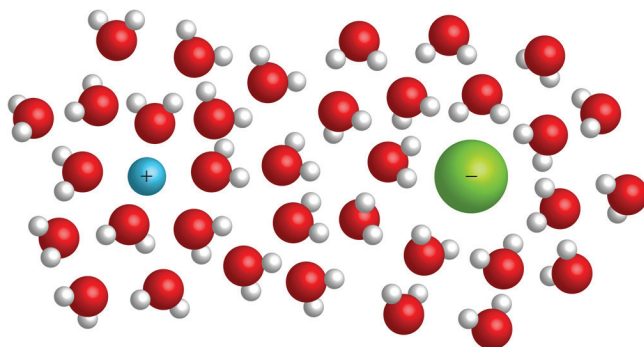


Figure D.40 Diagram of interaction between ion and dipole.

Dipole radiation

[electromagnetism, general] The steady-state charge configuration of a DIPOLE constitutes a constant electric field configuration, both in time and in space. Moving charges (i.e., current) provide a changing electric field that can be periodic in time, oscillating. The moving charges and associated current induces an alternating MAGNETIC FIELD, which combined with the alternating synchronized electric field generates electromagnetic (EM) RADIATION, that is, RADIO and television waves. The electric and magnetic field lines generated by the oscillating charges obey the standard MAXWELL EQUATIONS and are perpendicular to each other at all times. Naturally occurring EM radiation originates, for instance, from the partial displacement of the center of the positive and NEGATIVE CHARGE “cloud” on atomic and molecular scale. Assuming a stable ELEMENT, the charges are distributed with the POSITIVE CHARGE in the NUCLEUS and the negative (electron) charge in stable orbit around the nucleus. Disrupting the charge balance by removing an electron from orbit, specifically converting the “free” electron to another element (i.e., ION) will temporarily or permanently form a dipole. The temporary dipole creates the platform for atomic dipole EM emission (see Figure D.41).



Figure D.41 Dipole radiation emitted from analog radio antenna.

Dipole–dipole interaction

[chemical, nuclear, solid-state] The forces between two polar molecules, respectively, the positive and negative side of either. These forces are Coulomb forces and are attractive and strong, ranging from 5 kJ/mol to

20 kJ/mol. The potential energy in the interaction is captured by the COULOMB POTENTIAL between the two net charges of the respective POLES of the individual dipoles. WATER (H_2O) provides an excellent example, as does hydrogen chloride (HCl).

Dirac, Paul Adrien Maurice (1902–1984)

[atomic, computational, mechanics, nuclear, quantum, relativistic, thermodynamics] A theoretical physicist from Great Britain. The work of Paul Dirac combined with the efforts of ERWIN SCHRÖDINGER (1887–1961) resulted in them sharing the Nobel Prize for Physics in 1933. Paul Dirac combined the knowledge of JAMES CLERK MAXWELL (1831–1879) on QUANTUM THEORY with special relativity to form the concept of QUANTUM ELECTRODYNAMICS (see Figure D.42).



Figure D.42 Paul Adrien Maurice Dirac (1902–1984) at the 1927 Solvay conference on “Quantum Mechanics.”

Dirac delta function

[computational] A generalized function that is zero everywhere except for the (transformed) coordinate zero $\delta(\vec{r} - \vec{r}') = (1/2\pi) \int_{-\infty}^{\infty} e^{ip(\vec{r} - \vec{r}')} dp$, where $\delta(\vec{r} - \vec{r}') = 0$ for $\vec{r} - \vec{r}' \neq 0$ and $\delta(\vec{r} - \vec{r}') = +\infty$ for $\vec{r} - \vec{r}' = 0$ (see Figure D.43).

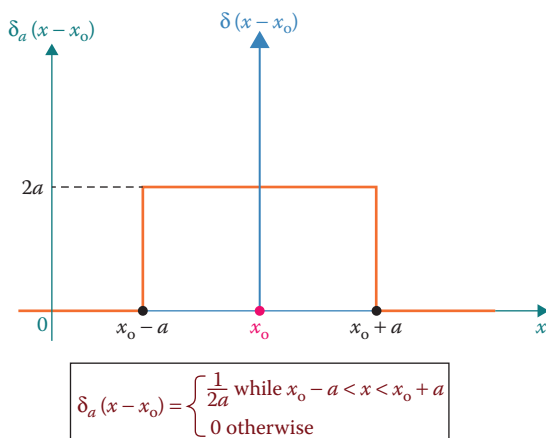


Figure D.43 Dirac delta function.

Dirac equation

[general, nuclear, quantum] Combining the concepts of the SCHRÖDINGER EQUATION with QUANTUM THEORY and special relativity yields a relativistic WAVE EQUATION that provides a DENSITY FUNCTION ($\Psi(\vec{x}, t)$, as function of space $\vec{x} = (x, y, z)$ and time t) of the PROBABILITY of the location of a PARTICLE in MOTION (predominantly moving at extremely high velocities on the order of the speed of light).

The wave function specifically applies to the electron orbital motion. The concept was derived from the ENERGY equation $E^2 = c^2 p^2 + m^2 c^4$ with speed of light $c = 2.99792458 \times 10^8$ m/s, $p = \hbar k$, $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck's constant, p the momentum of a particle in motion (*Note*: this function also identifies the momentum operator in the Schrödinger equation), $k = 2\pi/\lambda$ the WAVE NUMBER (also referred to as wave vector) for a wave function with wavelength λ , m the particle REST MASS. The energy equation theoretically yields two solutions, positive and negative. The concept of negative energy is not permitted in classical MECHANICS, while in QUANTUM MECHANICS (quantum ELECTRODYNAMICS), this negative energy (i.e., “holes” as devised at the time) occupied virtual space that was ideologically converted into POSITIVE CHARGE, the antielectron later confirmed as the positron by CARL DAVID ANDERSON (1905–1991). The Dirac equation for a particle with spin 1/2 (such as the ELECTRON and the QUARKS) is expressed as $(\beta mc^2 + \sum_{i=1}^3 \alpha_i p_i c) \Psi(\vec{x}, t) = i\hbar (\partial \Psi(\vec{x}, t) / \partial t)$, which provides a 4×4 matrix, summarized over the three DEGREES OF FREEDOM (i), with

$$\beta = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

and α_i coefficients that conform to the boundary conditions:

$$\alpha_1 = \begin{bmatrix} 0 & \sigma_x \\ \sigma_x & 0 \end{bmatrix}, \alpha_2 = \begin{bmatrix} 0 & \sigma_y \\ \sigma_y & 0 \end{bmatrix}, \text{ and } \alpha_3 = \begin{bmatrix} 0 & \sigma_z \\ \sigma_z & 0 \end{bmatrix}$$

Pauli spin matrices with SPIN σ_i .

Dirichlet, Peter Gustav Lejeune (1805–1859)

[computational] A mathematician and scientist from Germany (French Empire/Prussian Empire) dedicated to analytical number theory, also referred to as arithmetic. Arithmetic deals with whole numbers and has traceable roots dating back to documentation (clay tables) from approximately 1800 BC (see [Figure D.44](#)).



Figure D.44 Drawing of Peter Gustav Lejeune Dirichlet (1805–1859).

Dirichlet boundary condition

[computational, electromagnetism, fluid dynamics, mechanics, thermodynamics] Boundary conditions named after the work by PETER GUSTAV LEJEUNE DIRICHLET (1805–1859) that define the limitations to

an ordinary or partial differential equation at the edges of the domain for the boundary of the solutions. The Dirichlet boundary conditions apply to cases where the following conditions determine to process, for instance, a surface maintained at a fixed temperature; an electric junction at a fixed voltage; in FLUID FLOW the boundary will have a no-slip condition, with ensuing zero velocity at the boundary; and a geometric construction that is fixed at one end. The Dirichlet boundary condition is captured by $\nabla^2 f(\vec{r}) + f(\vec{r}) = 0$, which for the ordinary form is written as $f''(\vec{r}) + f(\vec{r}) = 0$ and ∇^2 is the Laplacian differential operator.

Dirichlet distribution

D

[computational] A discontinuous collection of multivariate PROBABILITY distributions, frequently denoted as $Dir(\vec{\alpha})$, where $\vec{\alpha}$ are positive real number vectors ($\vec{\alpha} = (\alpha_1, \alpha_2, \dots, \alpha_i, \dots, \alpha_K)$). The probability function is described as $Dir(\vec{\alpha}) = \left[\prod_{i=1}^K \Gamma(\alpha_i) / \Gamma \sum_{i=1}^K \alpha_i \right]^{-1} \prod_{i=1}^K x_i^{(\alpha_i-1)}$, with K the number of categories ($K \geq 2$), $\sum x_i = 1$, $\Gamma(x) = (n-1)!$ with n a positive integer or for complex numbers $\Gamma(x^*) = \int_0^\infty t^{x^*-1} e^{-t} dt^*$, the gamma function, describing the probability components, and α_i concentration or weight parameters. The “mode” of the distribution function is defined by $x_i = (\alpha_i - 1) / \sum_{i=1}^K \alpha_i - K$, setting $\alpha_i > 1$. The entropy of this distribution is $H(X) = \log B(\vec{\alpha}) + (\alpha_0 - K) \psi(\alpha_0) - \sum_{j=1}^K [(\alpha_j - 1) \psi(\alpha_j)]$, where $\psi(\alpha_j)$ is the digamma function ($\psi(x) = (d/dx) \ln[\Gamma(x)] = [\Gamma'(x)/\Gamma(x)]$) and $B(\vec{\alpha}) = \prod_{i=1}^K \Gamma(\alpha_i) / \Gamma \sum_{i=1}^K \alpha_i$. The Dirichlet probability function is also found, defined as $Dir(\vec{\alpha}) = \lim_{m \rightarrow \infty} \lim_{n \rightarrow \infty} [\cos^{2n}(m! \pi \vec{\alpha})]$, plotted as a discrete “AMPLITUDE” for probability as a function of location $\vec{\alpha}$ (see Figure D.45).

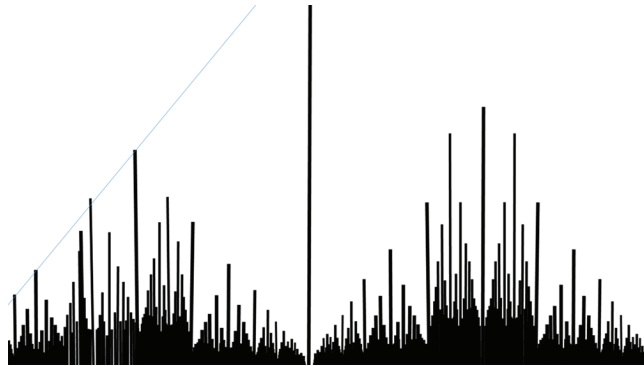


Figure D.45 Discrete Dirichlet distribution.

Discrete vortex

[computational, fluid dynamics] The theoretical approach to the turbulent FLOW across a vertical plane with respect to the surface of the WING of a plane, however at a significant DISTANCE behind the wing (i.e., Trefftz plane). The approximations for solving the flow pattern are that each aerodynamic surface is outlined by vortices in the shape of discrete horseshoe geometry. The collection of discrete vortices is defined by the Kutta–Joukowski theorem and obeys the BIOT–SAVART LAW. The Kutta–Joukowski theorem describes the CIRCULATION and is generally solved numerically (see Figure D.46).

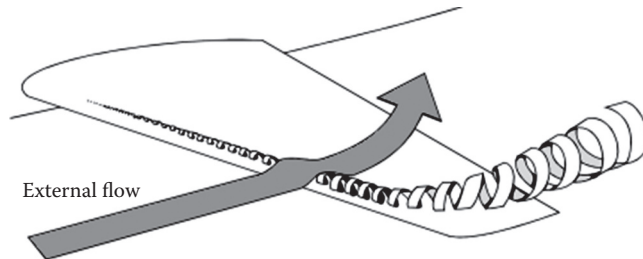


Figure D.46 Discrete vortex formed over a wing.

Dispersion

[computational, general, optics] Waves are identified by both a **PHASE VELOCITY** and a group velocity. Under conditions of inhomogeneity and anisotropy, the group **VELOCITY** (v_g) will be a function of the **WAVELENGTH** (λ): $v_g = d\omega/dk = v + (dv/dk)$, where $\omega = (2\pi\lambda/c) = 2\pi\nu$, $k = 2\pi/\lambda = \omega/v$, ν is the frequency, and $c = \sqrt{\mu_0\epsilon_0} = (\mu_0\epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s is the speed of light. Respectively, the phase velocity $v_g = \omega/k$. The dispersion thus results in speed of propagation differences as a function of wavelength, specifically applied to a waveform that is constructed from superposition of multiple waves with different wavelengths (e.g., **WHITE LIGHT**). In 1875, the Scottish physicist **JOHN KERR** (1824–1907) demonstrated the induction of anisotropy in **GLASS** with index of **REFRACTION** $n = n(\lambda)$ under the influence of an external electric field (**KERR EFFECT**, *also see* **KERR CELL**). The index of refraction for most transparent materials is a function of wavelength, providing a mechanism resulting in spectral spread for white light, or general broad band source. A specific example of anisotropy is found for the material calcite. For a **PRISM**, the deviation **ANGLE** (δ) for the ray of light at a particular **WAVELENGTH** (λ) exiting from the prism with respect to the vector of the incident ray provides the dispersion: $D_{\text{prism}} = d\delta/d\lambda = (d\delta/dn)(dn/d\lambda)$. The latter condition introduces the condition of Cauchy for the index of refraction as a function of wavelength as $n = C + (B/\lambda^2)$, with B and C material-specific constants. Dispersion in imaging introduces the concept of **CHROMATIC ABERRATION**. In case the phase velocity decreases with increasing frequency, the dispersion is referred to as normal dispersion, whereas an increase is defined as anomalous dispersion (*also see* **WAVE DISPERSION** and **KRAMERS–KRONIG RELATIONS**) (see [Figure D.47](#)).

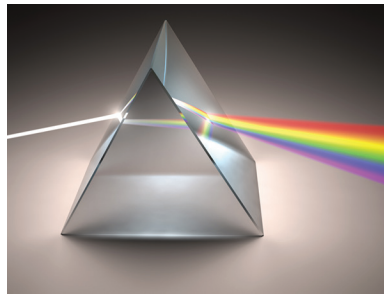


Figure D.47 Wavelength-dependent propagation leading to dispersion in a prism.

Distance

[general] The length of separation between two objects, unit meter. The meter was originally defined in 1799 as one-ten millionth of the distance from the **NORTH Pole** to the equator along the meridian that runs through Paris. In 1960, the meter was redefined under the **Système International (SI)** unit scheme as the length of a stick of alloy composed of platinum–iridium under normal conditions (20°C; 1 atm; 60% **HUMIDITY**), also on file in Paris. Later that decade, the krypton-86 **ISOTOPE DECAY** emission **WAVELENGTH** (orange–red: 605.78 nm) was used to define the unit length, and currently, the distance traveled by **ELECTROMAGNETIC RADIATION** sets the standard for a time frame of $1/299792458$ s. Early definitions of length involve the distance between the tip of the middle finger of the stretched arm of King Henry I of England to the tip of his nose, as documented in 1120, this being the yard. The early Greek units of measure were dimensions related to body parts, such as the digit of a finger (approx. 19 mm), the length of

a foot (which is 1% longer than the foot in the English system of measurements), and the fathom (approx. 180 cm) described in 450 BC (see [Figure D.48](#)).



Figure D.48 Sign post with distances to remote locations.

APPROXIMATE DISTANCE OR SIZE FOR OBJECT	VALUE [M]
Earth to known quasar at greatest distance	1.4×10^{26}
Earth to known most remote galaxy	9×10^{25}
Earth to Andromeda (closest galaxy; M31)	2×10^{22}
Sun from nearest star (Proxima Centauri)	4×10^{16}
Earth's orbit radius	1.5×10^{11}
Earth mean radius	6.3×10^6
Average human	1.6
Sparrow	1.5×10^{-2}
Average cell diameter	1×10^{-5}
Blue light wavelength	3.30×10^{-7}
Hydrogen atom diameter	1×10^{-10}
Hydrogen nucleus	1×10^{-14}
Neutron	1×10^{-15}

Distillation

[thermodynamics] A selective condensation of LIQUID constituents from a mixture (e.g., separate ALCOHOL from water, OIL refinement for separation into fossil fuels, and raw ingredients for polymerization). In a distillation column, a mixture of fluids is introduced in a column that has several stages arranged in horizontal planes at increasing altitude that operate in mutual equilibrium between the liquid and the vapor PHASE. The more volatile constituent (lower vapor point) is evaporated as BUBBLES upward to the next higher stage, eventually making its way to the top of the column, while the condensate that has been depleted of the more volatile components will drain back down to the bottom of the column, where the

“SOLVENT” can be drained off. The evaporated more volatile constituent can be vented and collected at the top of the column (*also see* DEW LINE) (see [Figure D.49](#)).



Figure D.49 (a) Picture of an old-fashioned “moon-shine” distillery (Courtesy of Southwestern Distillery, Cornwall, United Kingdom.) and (b) modern large volume copper distillery.

Diurnal

[biomedical, energy, geophysics] Daily (diurnal cycle) or related to ACTIVITY occurring primarily in the daytime (e.g., flowers closing at night) (*also see* CIRCADIAN RHYTHM) (see [Figure D.50](#)).



Figure D.50 Diurnal events: sunrise at Mount Fuji, Japan.

Diurnal arc

[biomedical, energy, geophysics] The daily time frame that a celestial body is above the horizon for the observer (e.g., the daily cycle of the SUN has a diurnal arc lasting from sunrise to sunset).

Divergence

[biomedical, computational, fluid dynamics, optics] The vector spread due to a computational algorithm or due to a device. A LENS with a negative focal length will provide divergence of the optical rays, forming a virtual IMAGE. An EXPANSION with gradual or discrete increase in diameter with increasing DISTANCE from a reference point following a cylindrical flow will result in diverging flow or general mass movement. Divergence represents the vector density (e.g., flow density) as a function of volume with respect to a vector field initiating from an infinitesimal volume. Computationally, this is captured by the vector operator gauging the MAGNITUDE of the source or sink for a vector field ($\vec{F}_v$), expressed by $\text{div } \vec{F}_v(\vec{p}) = \nabla \cdot \vec{F}_v(\vec{p}) = \lim_{V \rightarrow \{\vec{p}\}} \iint_{S(V)} (\vec{F}_v \cdot \vec{n} / |V|) dS \cong \lim_{\Delta V \rightarrow 0} \{(1/\Delta V) \oint_S \vec{F}_v \cdot d\vec{S}\}$, where $\nabla = (d\vec{F}/dx) + (d\vec{F}/dy) + (d\vec{F}/dz)$, $m = \rho V$ is the mass, ρ is the density (respectively, line density [vector field] or mass density [flow]), V is the local volume, with respect to points in space $\vec{p}$ that identifies the origin of the vector field (e.g., “source” of flow), note that $\Delta V \rightarrow 0$ implies convergence on the “origin,” S is the surface of the boundary of the volume V , with $\vec{n}$ the normal to this surface. In case the flux-density vector $\vec{F}_v$ describes the FLOW of charge (current) or mass (FLUID), the closed integral signifies the deviation from the CONSERVATION OF MASS with respect to the volume enclosed. The flow of mass can be represented by a velocity field $v(x, y, z, t) \sim v(r, \theta, \phi, t)$ leading to $\oint_S \rho \vec{v} \cdot d\vec{S} = -\int_{\Delta V} (\partial \rho / \partial t) dV$, which yields the EQUATION OF CONTINUITY under Gauss’s theorem $\nabla \cdot (\rho \vec{v}) = -(\partial \rho / \partial t)$, where ρ is a function of location. Applying the Stokes theorem, the convergence also implies $\int_{\Delta S} \nabla \times \vec{F}_v \cdot d\vec{S} = \oint_L \vec{F}_v \cdot d\vec{\ell}$, with L the circumference of the closed loop, and $\vec{F}_v \cdot d\vec{\ell}$ may need to be developed into a series $\vec{F}_v \cdot d\vec{\ell} = (\vec{F}_v + (d\vec{F}_v/dx)\Delta x + \dots)\Delta y$ for approximate analog solving for the divergence (see Figure D.51).



Figure D.51 Divergence.

Divergence-free vector field

[computational, fluid dynamics] A fundamental component of HELMHOLTZ DECOMPOSITION in vector calculus. In a three-dimensional space, the vector field ($\vec{V}$) composed of sufficiently smooth, rapidly decaying vectors can be decomposed into the sum of two “orthogonal” components, one consisting of an IRROTATIONAL (CURL-FREE) VECTOR FIELD and the second segment composed of rotational (divergence-free) or solenoidal vector field. The formulation of this series is defined as a function of location ($\vec{r}$) within a volume in space (V) as $\mathbb{D} = (1/4\pi) \int_V \nabla' \times \vec{V}(\vec{r}') / |\vec{r} - \vec{r}'| dV' + (1/4\pi) \int_S \vec{V}(\vec{r}') \times d\vec{S}' / |\vec{r} - \vec{r}'|$. The second term will have limit zero when the phenomenon comprises all of free space with the vector field rapidly decreasing.

Divergenceless

[computational] A vector field that implies charge conservation $(\partial/\partial t)\vec{J} + \nabla \cdot \vec{J} = 0$, where $\vec{J}$ represents the charge FLOW density. For a general steady-state vector field ($\vec{F}_v$), the concept of divergenceless entails $\nabla \cdot \vec{F}_v = 0$, which means that there exists a function $\vec{G}$ that provides $\vec{F}_v = \nabla \times \vec{G}$, also referred to as a SOLENOID field (as introduced by SIR HORACE LAMB [1849–1934] in 1932) (also see DIVERGENCE-FREE VECTOR FIELD and EARNSHAW'S THEOREM).

Divergent flow

[fluid dynamics] A FLOW that proceeds with a diminishing vector density at greater DISTANCE from the exit point (see DIVERGENCE).

Diverging lens

[general, optics] A LENS that will form a virtual IMAGE, diverging rays of light emanating from the lens under illumination by a directional source. A parallel ray entering the lens will emerge with a positive ANGLE with respect to the optical axis, also referenced as a lens with a negative focal length. This applies to optical lenses, magnetic, and electronic lenses (see LENS).

Diverging waves

[fluid dynamics] Free SURFACE WAVES can be regarded as diverging waves in a circular path (of uniform depth). As such, TIDAL WAVES behave as long waves on a plane sheet of water, which can be approached as a steady-state WAVE propagating in the r -direction. This problem is presented as $(d^2\phi_w/dr^2) + (1/z)(d\phi_w/dr) + \phi_w = 0$, where ϕ_w represents the VELOCITY POTENTIAL of the surface. In an asymptotic SOLUTION, the diverging wave solution incorporates a zero-order Bessel function of the first kind $J_0(r) = (2/\pi) \int_0^\infty \sin(z \cosh \xi) d\xi$, where ξ is the ANGLE in the complex plane (representing DIVERGENCE) expressed in series approximation as $\phi_w^0(\chi r) = (1/4) \left\{ (2/\pi) (\log(\chi r/2) + \gamma_w + (1/2)i\pi) J_0(\chi r) - (2/\pi) [(\chi^2 r^2/2^2) - s'_2(\chi^4 r^4/2^2 2^4) + s'_3(\chi^6 r^6/2^2 2^4 2^6) - \dots] \right\} e^{i\omega t}$, where $\chi = \omega/\sqrt{gb}$ is the WAVE NUMBER (wave propagation velocity: $v = \sqrt{gb}$, g is the GRAVITATIONAL ACCELERATION, b is the height of the water [depth], $\omega = 2\pi\nu$ is the ANGULAR FREQUENCY, ν is the OSCILLATION frequency [applied external “pressure” oscillation]), γ_w is the integration constant for the real part [derived from $\int_{r/2}^\infty (e^{-\xi}/\xi) d\xi = -\gamma_w - \log(r/2) + \text{Rest}$; Rest represents a rest term], and $s'_i = 1 + \{(1/2) + (1/3)\} + \dots + (1/i)$ is a NORMALIZATION constant respectively air/water where ϕ_w represents the wave phenomenon. On the other hand, a diverging wave in AIR will be a three-dimensional process, expressed as a SPHERICAL WAVE obeying (in spherical coordinates) $(\partial^2\phi_a/\partial t^2) - 2(\partial\phi_a/\partial r)(\partial^2\phi_a/\partial r\partial t) + (\partial\phi_a/\partial r)^2(d^2\phi_a/dr^2) = v_s^2[(\partial^2\phi_a/\partial r^2) + (2/r)(d\phi_a/dr)]$, where ϕ_a represents the velocity potential of the air volume, $v_s \sim \sqrt{P_0/\rho_0}$ is the speed of SOUND, P_0 is the pressure, ρ_0 is the density, derived from the velocity potential (ϕ_a) through $v_s^2 c_s = (\partial\phi_a/\partial t)$, with c_s the “condensation,” which is an indication of the AMPLITUDE of the pressure. For a simple HARMONIC OSCILLATION with frequency $\nu = v_s/\lambda$ (λ is the wavelength), the solution is rather conveniently written as $\phi_a = e^{-ikr}/4\pi k$,

where $k = 2\pi/\lambda$ is the wave number. A rather complex solution for a complex disturbance is described in detail dedicating book volumes to this problem (see [Figure D.52](#)).

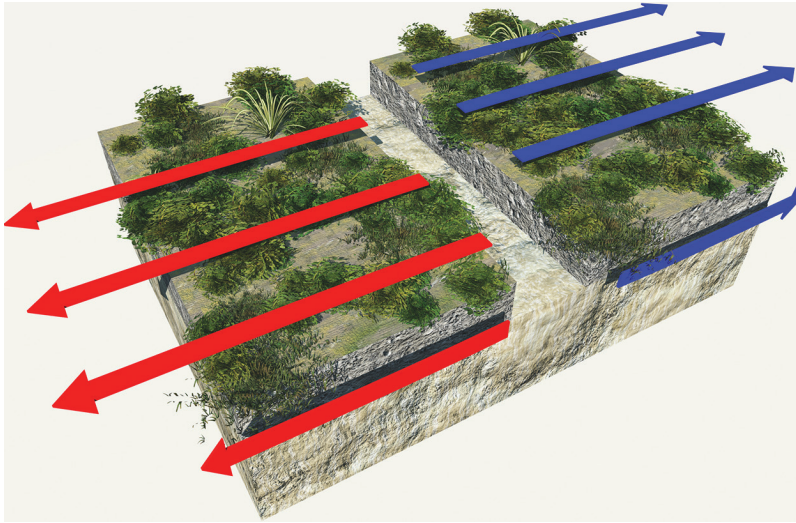


Figure D.52 Divergent wave separating tectonic plates during earthquake.

DNA

[biomedical, chemical, general, theoretical] Deoxyribonucleic ACID (genetic molecule). DNA contains the information about the species and the construction details for functional components (i.e., organs), the hereditary information. DNA is contained in the cellular chromosome. DNA was identified and isolated by the Swiss physician FRIEDRICH MIESCHER (1844–1895) in 1868. DNA is constructed of four elementary molecular chains: guanine (G), adenine (A), thymine (T), and cytosine (C). The molecular structure of DNA was discovered by ROSALIND FRANKLIN (1920–1958) in 1951. In general, the DNA molecules are comprised of two biopolymer strands. The strands are coiled around each other to form what is known as the double helix. The double-helix structure of DNA was unraveled based on the efforts from Rosalind Franklin by the American molecular biologist JAMES D. WATSON (1928–) and the English molecular biologist and biophysicist FRANCIS HARRY COMPTON CRICK (1916–2004) in 1953. DNA is contained in every living CELL of all organisms and viruses. The DNA is apparently involved in a communication system (chemical, electronic, and potentially optically) that allows individual cells to split, congregate (cell proliferation), and form a specific structure, based on their location with respect to neighboring cells. DNA performs a process of chemical encoding, decoding, and regulation. With each cell division, all material in the cell is duplicated. The cell duplication process is initiated by a DNA synthesis process, the DNA coils split longways, and a messenger RNA (ribonucleic acid) is formed that reproduces the identical DNA

strand. The nucleic acids DNA and RNA in combination with proteins form the essential constituents and foundation of life (see [Figure D.53](#)).

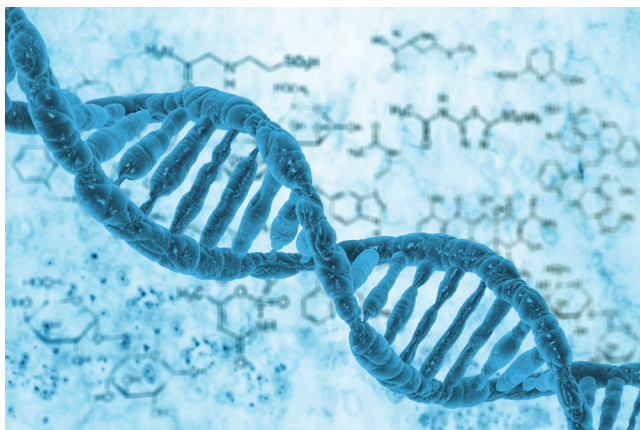


Figure D.53 The complex structure of the DNA molecular chain.

Dolphin

[general] A sea mammal that relies on ultrasonic detection for orientation and guidance. The DOLPHIN ultrasound is comprised of short chirp WAVE trains with a wavelength of approximately 1.4×10^{-2} m (see [Figure D.54](#)).



Figure D.54 Dolphins.

Donnan, Frederick George (1870–1956)

[biophysics, chemical, electromagnetism, energy] A physical chemist from Ireland. Frederick Donnan is best known for his work on the chemical equilibrium at the cellular MEMBRANE in biological media. The DONNAN EQUILIBRIUM describes the ION transportation across the CELL MEMBRANE (see [Figure D.55](#)).



Figure D.55 Frederick George Donnan (1870–1956). (Courtesy of *Journal of Chemical Education*, 4[7], 1927.)

Donnan equilibrium

[biophysics, chemical, electromagnetism, energy] A chemical equilibrium across the MEMBRANE of biological tissues as derived by FREDERICK DONNAN (1870–1956).

Doping

[atomic, electronics, energy, general] Introduction of a foreign ATOM in the atomic structure of a semiconductor throwing the electron balance off, which increases the PROBABILITY of an electron to move from the VALENCE BAND to the CONDUCTION BAND (electron surplus: N-TYPE) or vice versa (electron shortage or “electron-hole” [hole] surplus: P-TYPE).

Doppler, Christian Johann (1803–1853)

[acoustics, mechanics, optics] A physicist from Austria who explained the changes on observed SOUND frequency resulting from MOTION in 1842. For instance, when waiting at a railroad crossing while a train is approaching that blows its whistle, the sound will be higher on approach than on departure with respect to the location of the observer. In actuality, the sound generated by the train while increasing its DISTANCE is lower than the sound acquired when the train and the observer are fully aligned (see [Figure D.56](#)).



Figure D.56 Christian Doppler (1803–1853).

Doppler

[acoustics, biomedical, biophysics, electromagnetism, engineering, imaging, instrumentation, theoretical] A FREQUENCY (f or ν) shift resulting from relative MOTION between source and observer. This frequency phenomenon was described by the Austrian physicist CHRISTIAN JOHANN DOPPLER (1803–1853) in 1842. The Doppler effect holds true for all types of waves. When light interacts with moving objects or if the LIGHT SOURCE itself is moving, there will be a frequency shift. This frequency shift has been described in various textbooks for both SOUND and light. The underlying principle to the frequency shift with regard to a moving source or observer is the fact that the perceived wavelength will be caught at progressively earlier (respectively later) PHASE intervals when source and observer are moving toward (respectively away from) each other. We leave the derivation of the expression to the basic PHYSICS textbooks and will only show the final statement for a frequency shift resulting from both moving source and observer. The perceived frequency by the observer in relative motion to the source is given by $f' = \left[\left(1 \pm \frac{u_o \cos(\theta)}{c'} \right) / \left(1 \mp \frac{u_s \cos(\theta)}{c'} \right) \right] f = f + \Delta f$, where f is the frequency of light, u_o is observer velocity, or the speed of the modulation device in the detector arm, u_s is the source velocity, or the speed of the modulation device in a reference arm of the detector arrangement, c' is the speed of light in the medium. The signs on top, for the numerator: $\pm$, and for the denominator: $\mp$ respectively, are for the situation where the source is moving toward the detector and the signs on the bottom means that the source is moving away from the observer. One will try to ensure that multiple modulations will synchronize and reverse direction simultaneously within in one period. The term $\cos(\theta)$ represents the component normal to the source (see Figure D.57).



Figure D.57 Doppler effect.

Double-slit experiment

[general, optics] See THOMAS YOUNG DOUBLE-SLIT EXPERIMENT.

Doublet

[fluid dynamics] Flow velocity field potential (ϕ) that has a clockwise rotation in the upper quadrant versus a counterclockwise rotation in the bottom quadrant. In this situation, the streamlines (ψ) are represented as $\psi = -(A/r)\sin\theta$, where A represents the AMPLITUDE, r is the radial location, and θ the angular orientation.

Doublet state

[atomic, chemical, nuclear] Quantum-MECHANICAL ENERGY configuration that describes a system with a SPIN of $1/2$, consequently providing two spin components, respectively: $-1/2$ and $+1/2$. One example of the influence of the quantum state doublet is found for sodium, specifically the transition from 3p (QUANTUM NUMBER $\ell = 1$) to the 3s level (quantum number $\ell = 0$), where the 3p state has two states: $j = 3/2$ and $j = 1/2$ with ensuing spin-orbit split yielding two spectral lines 589.0nm and 589.6nm, respectively. The difference in energy (ΔE) for the doublet is defined by the BOHR MAGNETON (μ_B), the ELECTRON SPIN factor g^* , and the MAGNETIC FIELD (B) required to produce this split: $\Delta E = \mu_B g^* B$. Based on the emission line energy difference, the magnetic field strength can be determined (*also see* ZEEMAN EFFECT).

Down quarks

[general] A QUANTUM condition of elementary PARTICLE. Quarks can have six (6) “flavors”: up, down, strange, charmed, bottom, and top (*see* QUARK).

Drag

[fluid dynamics, mechanics, thermodynamics] *Also* DRAG FORCE: a FRICTION force or resistive force, primarily velocity dependent $F_d = F_F = -b_F v$, where b_F is a geometric coefficient relating the shape and size of the body in MOTION to the motion as well as the characteristics of the media in contact, and v is the relative velocity of the body in motion with respect to the surroundings, primarily FLUIDS. It is also defined as the resistive force that is proportional to the area of the object (A) in relative motion with respect to a FLUID medium with relative VELOCITY v , multiplied by the DRAG COEFFICIENT, which is also dependent on the velocity, the DENSITY of the object (ρ) and fluid, respectively, as well as size and shape of the object. The drag force is in the opposing direction of the relative FLOW velocity: $\vec{F}_d = -(\rho v^2 C_d A / 2) \vec{e}_v$, where $\vec{e}_v$ represents the unit vector for the flow direction (*also see* DRAG COEFFICIENT [C_d]). An object exposed to drag in free fall will eventually reach TERMINAL VELOCITY under balancing forces, instead of continuously accelerating under the influence of the governing acceleration phenomenon (primarily GRAVITATION, e.g., dropping a ball from the Eiffel Tower) (*see* Figure D.58).



Figure D.58 The concept of drag visually interpreted.

Drag coefficient ($C_D = F_D / [((1/2)\rho v^2)(\pi R^2)]$)

[fluid dynamics, mechanics] A dimensionless number expressed as the quotient of the DRAG force with respect to the kinetic ENERGY multiplied by the cross-sectional area of the object exposed to FLOW. When considering a sphere with radius R subjected to a flow with velocity v in a FLUID with density ρ while subjected to a measured drag force F_D . Certain objects have their own drag coefficient, primarily due to the frequent computational efforts on the subject. To list a few specific drag coefficients, the following are representative: the drag coefficient of a cone (C_D), drag hemisphere, cylinder, oblong board, and passenger car. One of the lowest drag coefficient mass-produced automobiles is the Mercedes CLA (see Figure D.59).



Figure D.59 Mercedes CLA with $C_D = 0.23$. (Courtesy of Daimler AG.)

Drag coefficient ($C_d = g(\rho - \rho_f)L/\rho v^2$)

[mechanics] The quotient of gravitational force over inertial force (-density) applied during resistive FLOW and settling velocities due to DRAG, where g is the GRAVITATIONAL ACCELERATION, L is characteristic length, ρ is the object density, ρ_f is the FLUID density, and v is the velocity.

Dreyer, John Louis Emil (1852–1926)

[astronomy, astrophysics, general] An astronomer from Denmark. John Dreyer is known for his validation work on the observations made by TYCHO BRAHE (1546–1601). He also made several distinguished observations about the surface structure on the MOON and has one crater named after him (see [Figure D.60](#)).

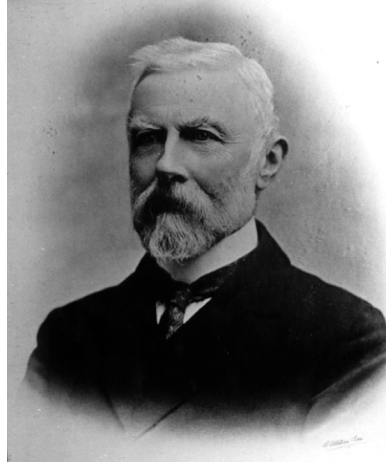


Figure D.60 John Louis Emil Dreyer (1852–1926).

Drift

[biomedical, mechanics] Small eye-movements in the classification of fixation on a point. Other classifications are micro-SACCADE (jerky) and TREMOR.

Drift velocity

[electromagnetism, general] Average VELOCITY (v_d) of charged particles, specifically electrons, under the influence of an external ELECTRIC FIELD (E): $v_d = \mu_{\text{ch}} E = M_{\text{conductor}} V / \rho_c N_A \ell e n_f \rho'_0 (1 + \alpha_0 T)$, where μ_{ch} represents the “mobility” of the charged PARTICLE, $M_{\text{conductor}}$ is the MOLAR MASS of the CONDUCTOR, ρ_c is the density of the conductor, V is the applied electrical potential, N_A is the Avogadro’s number, e is the fundamental electron charge, ℓ is the length of the conductor, n_f is the atomic number of VALENCE electrons that can be released as free electrons, T is the temperature of the conductor (METAL), and α_0 is the temperature coefficient for the SPECIFIC RESISTANCE of the conductor. The associated current density (J_e) is expressed as $J_e = \rho v_d$, where ρ is the charge density.

Driven damped harmonic oscillator

[acoustics, atomic, electromagnetism, fluid dynamics, general, mechanics, nuclear] A harmonic OSCILLATOR that is under continuous periodic externally applied excitation force with additional dampening force applied. The OSCILLATION can be electronic in an electronic LRC (L: INDUCTOR; R: RESISTOR; C: CAPACITOR) circuit or mechanical. The mechanical force may be the AIR stream blowing over a reed in a clarinet. Any driven damped harmonic oscillator can be described by an ordinary differential equation with respect to the ANGLE of rotation (ϕ) as $(\partial^2 \phi / \partial t^2) + 2\gamma_d (\partial \phi / \partial t) + \omega_0^2 \phi = A_0 \cos(\omega_d t)$ for a driven oscillation with frequency ω_d , AMPLITUDE A_0 , with dissipation γ_d , for a system with NATURAL FREQUENCY $\omega_0 = 2\pi\nu$, ν the frequency as a function of time t . Generally, the amplitude of the damped oscillation is small and $\phi(t) \cong \sin \phi$. The SOLUTION to the WAVE EQUATION consists of two components: a homogeneous solution as well as a particular solution. In case the DAMPING is non-vanishing $\gamma_d > 0$, only the particular solution remains over time. The initial conditions will include the homogenous solution however, where $\partial \phi / \partial t|_{t=0} = v_0$ provides the initial velocity,

while the object is initially at rest $\varphi(0) = 0$. The transient period, leading to the particular solution is defined by the time constant $t \gg \gamma_d^{-1}$. During the transient process of the oscillation, there may be a PHASE shift θ , leading to the “proposed solution” for the amplitude $z(t)$: $z(t) = z_{\omega_d} \exp\{i(\omega_d t - \theta)\}$, with associated oscillation force $F_{\text{osc}} = A_0 e^{-i\omega_d t}$, providing $|z_{\omega_d}| = A_0 / \sqrt{[(\omega_d^2 - \omega^2)^2 + 4\gamma_d^2 \omega_d^2]}$. The persistence of the oscillation can be defined by the QUALITY FACTOR $Q = \omega_0 / 2\gamma_d$ (also see OSCILLATION) (see Figure D.61).

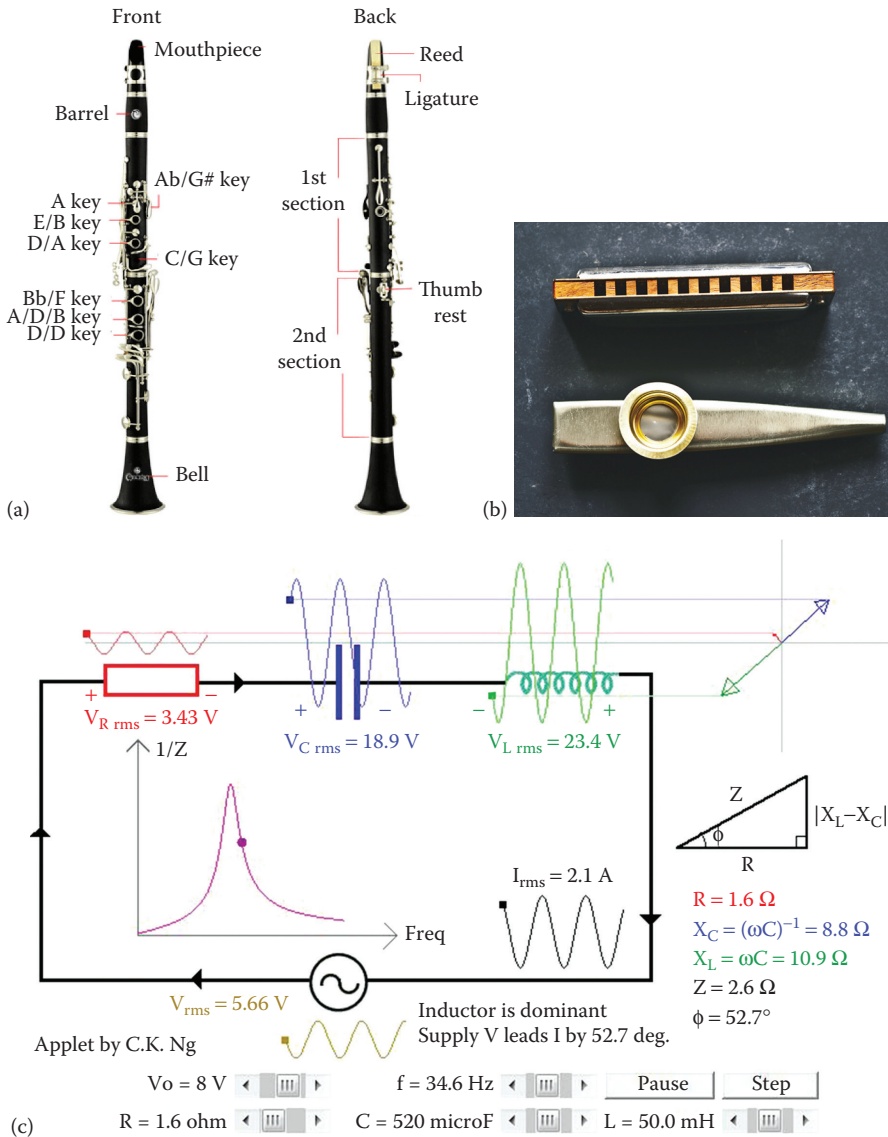


Figure D.61 Driven harmonic oscillator examples: (a) Clarinet and (b) Harmonica and Kazoo. (Courtesy of Chiu-king Ng, Hong Kong, China; <http://ngsir.netfirms.com>.) (c) RLC-circuit. (Courtesy of Chiu-king Ng, Hong Kong, China; <http://ngsir.netfirms.com>.)

Du Fay, Charles François de Cisternay (1698–1739)

[atomic, nuclear] A French botanist and chemist. His work contributed to the basic understanding of the atomic structure by describing the phenomenon of **ELECTRIC CHARGE**. Specifically his description of the charges with associated repulsion and attraction when rubbing a **GLASS** rod with silk and **AMBER** rubbed with fur between like materials and unlike materials, respectively, published around 1734 (see [Figure D.62](#)).



Figure D.62 Charles François de Cisternay du Fay (1698–1739).

Dubridge, Lee Alvin (1901–1994)

[atomic, nuclear] A physicist from the United States. Alvin DuBridge was involved in pioneering efforts on the **PHOTOELECTRIC EFFECT**.

Duhem, Pierre Maurice Marie (1861–1916)

[chemical, thermodynamics] A physicist from France. Pierre Duhem was an avid supporter of the concept that **THERMODYNAMICS** provided the foundations to all aspects of **PHYSICS** and **ENGINEERING**, “energetics.” Duhem’s work in chemistry and thermodynamics provides theoretical support for reversible

processes (*see* **DUHEM–MARGULES RELATION**). Additional work was in collaboration with WILLARD GIBBS (1839–1903), where Duhem provided proof for the Gibbs **PHASE RULE** (*see* [Figure D.63](#)).



Figure D.63 Pierre Maurice Marie Duhem (1861–1916), 1913.

Duhem–Margules relation

[thermodynamics] An equation describing the thermodynamic equilibrium between two constituents of a **FLUID** in comparison to the **VAPOR** mixture as proposed by **PIERRE DUHEM** (1861–1916) and **MAX MARGULES** (1856–1920).

Dull, Charles Elwood (1878–1947)

[general] A physicist from the United States. Charles Dull provided an elaborate description of “modern physics” in 1922.

Dulong, Pierre Louis (1785–1838)

[thermodynamics] A French physicist. Pierre Louis Dulong (1785–1838) is specifically known for his contributions to the **THERMODYNAMICS** of **SPECIFIC HEAT** and the **LAW OF DULONG AND PETIT** (*see* [Figure D.64](#)).



Figure D.64 Pierre Louis Dulong (1785–1838). (Courtesy of Wilhelm Ostwald; *Elektrochemie—Ihre Geschichte und Lehre*; Veit & comp., Leipzig, Germany 1896.)

Dulong–Petit law

[atomic, thermodynamics] The relation for the SPECIFIC HEAT under constant volume ($c_v = du/dT = T(ds/dT)$) asymptotically approaches the value of the universal GAS CONSTANT (R) (or Boltzmann constant for a molecular or atomic base, expressed per ATOM/molecule), however not limited to gaseous form. When the temperature (T) of the medium is much larger than the DEBYE TEMPERATURE (Θ_D), the specific heat reduces as $c_v(T) \cong 3R\{1 - (1/20)[\Theta_D/T]^2\} \rightarrow 3R$, established by PIERRE LOUIS DULONG (1785–1838) and ALEXIS PETIT (1791–1820) in 1819.

D

Dunning, John Ray (1907–1975)

[atomic, nuclear] A physicist from the United States who was instrumental in the development of the ATOMIC BOMB. Additional work by Dunning involved the development of the process for ISOTOPE separation by means of GAS DIFFUSION (see [Figure D.65](#)).



Figure D.65 John Ray Dunning (1907–1975) on the right along with Hubert Thelen taken in 1957.

Dushman, Saul (1883–1954)

[atomic, nuclear] A scientist from Russia. Dushman was a contemporary of WALTER SCHOTTKY (1886–1976), and he used his work in ELECTRON TUBE functionality formulation (*also see* EDISON EFFECT).

Dussik, Karl Theodore (1908–1968)

[acoustics, biomedical, imaging] A physician from Austria with a specialization in neurology. Dussik published the first use of high-frequency ACOUSTICS (now known as ULTRASOUND imaging) for imaging purposes in 1942. The work of Karl Dussik was inspired by his professional interest in the location of brain tumors (see [Figure D.66](#)).



Figure D.66 Karl Theodore Dussik (1908–1968).

Dynamics

[general, mechanics, thermodynamics] An investigation of the cause of MOTION (in contrast to KINEMATICS). The study of dynamics, for instance, includes the concepts of FORCE and MASS, NEWTON'S LAWS (incorporating for instance COLLISION), in addition to the characteristics of GRAVITATION. In greater detail, the phenomena of FRICTION and KEPLER'S LAW are part of this field of MECHANICS.

Dyne

[general] A unit of force that, when acting upon a mass of 1 g, will produce an acceleration of $1 \times 10^{-2} \text{ m/s}^2$.

Dynode

[electronics] An ELECTRODE that produces secondary electron emission in a VACUUM tube. Dynodes in a PHOTOMULTIPLIER TUBE are arranged at incremental electrical potential in order to provide an avalanche effect (see [Figure D.67](#)).



Figure D.67 Dynode vacuum tube.



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E

e

[electromagnetism, energy, general, thermodynamics] Electron, the fundamental nuclear PARTICLE. The existence of charges (disparity in charge to be exact) was first described in 1734 by the French botanist and chemist CHARLES FRANÇOIS DE CISTERNAY DU FAY (1698–1739), and later by BENJAMIN FRANKLIN (1706/1705?–1790) in 1760. The electron is on the outer shell of the ATOM with the PROTON and NEUTRON in the NUCLEUS of the atomic structure, as aptly described by the ATOM MODEL of NIELS HENRIK DAVID BOHR (1885–1962). The electron was described in detail with the associated effects by CHARLES-AUGUSTIN DE COULOMB (1736–1806) in the 1785 publication *Histoire et Mémoires de l'Académie Royale des Sciences*. The revelation of the electron charge formed the SOLIDIFICATION that charged object either attract or repel, depending on the respective charge configuration (“opposites attract”). The MAGNITUDE of the electron charge is expressed in COULOMB UNITS.

Eadie–Hofstee plot

[biomedical, chemical, computational] Reaction analysis for enzyme-catalyzed LIGAND binding processes. Graphical representation of the enzyme kinetics with respect to the ratio of the substrate dissipation rate ($V_{\max}$) and the substrate concentration ($[S]$) illustrating the reaction rate ($v_{\text{réact}}$), as $v_{\text{réact}} = -K_M (v_{\text{réact}}/[S]) + V_{\max}$, where K_M is the Michaelis–Menten constant, as derived from the MICHAELIS–MENTEN EQUATION. The plot can be used to identify the Michaelis–Menten constant (slope) (see Figure E.1).

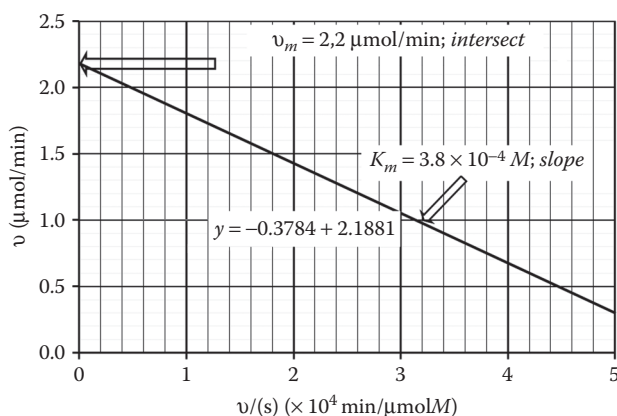


Figure E.1 Graphical representation of Eadie–Hofstee plot.

Ear

[acoustics, biomedical, general] Biological sensing device that can acquire PRESSURE WAVES (i.e., SOUND). The EAR has several structural components as well as various functional components. Structurally, the ear is divided in three segments: the OUTER EAR, the MIDDLE EAR, and the INNER EAR. The outer ear is the

exterior shell (pinna) with magnified areal size in comparison to the AUDITORY MEATUS or EAR CANAL to ensure effective and high PROBABILITY of collecting large MAGNITUDE pressure waves that captures the pressure waves and guides them into the AUDITORY CANAL leading to the middle ear. At the middle ear, the pressure variations are transferred into MECHANICAL VIBRATIONS of a solid. The middle ear is separated from the auditory canal by the TYMPANIC MEMBRANE or EAR DRUM the tympanic MEMBRANE is the percussion device that converts pressure variations into mechanical vibrations, facilitating further transfer to a LIQUID-filled sensory compartment (inner ear). Inside the middle ear, the tympanic membrane pushes against a LEVER system of three interlocking bones (the OSSICLES) to transfer the mechanical vibrations to the OVAL WINDOW of the inner ear. The bone structure components are (moving inward, respectively) the MALLEUS (hammer), connected to the INCUS (anvil) connected to the STAPES (stirrup), which is connected to the oval window. The middle ear is generally pressure stabilized by maintaining contact with the external pressure through the EUSTACHIAN TUBE, which connects to the nasal cavity. The SOUND intensity transferred in the middle ear is capable of being regulated by various means. The intrinsic regulation of energy transfer is in the aspect ratio of the components. Primarily, the ELASTICITY of the tympanic membrane can be controlled by pressure variations of the middle ear mediated by the Eustachian tube. The VIBRATION magnitude is controlled by spacing the three bones through MUSCULAR interaction (for instance, the malleus is attached to the TENSOR tympani MUSCLE), providing a means to control the LOUDNESS of the sound as well as offering protection from mechanical damage to the inner ear. The oval window is the passage to the inner ear, which consists of the COCHLEA. The cochlea doubles back to the final window, the round window, close to the oval window in the middle ear. The inner workings of the cochlea are described in detail in the entry for cochlea. The intricate mechanism of conversion of mechanical vibrations to electrical impulses is transmitted over the cochlear branch of the VESTIBULOCOCHLEAR NERVE for DATA ACQUISITION and SIGNAL PROCESSING by the BRAIN (*also see* HEARING). In addition to HEARING, the inner ear also has a construction attached that functions as a means to detect and preserve equilibrium (see [Figure E.2](#)).

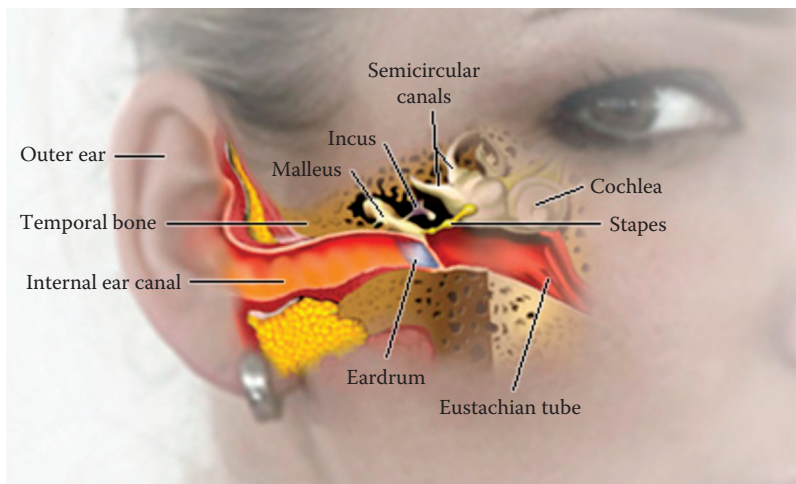


Figure E.2 Anatomy of the ear. Detailed illustration of working components of the ear: outer ear, middle ear, inner ear, and equilibrium system.

Earnshaw, Samuel (1805–1888)

[computational, electromagnetism, general] An English clergyman, mathematician, and mathematical physicist. Earnshaw made significant contributions to the theoretical description of passive MAGNETIC LEVITATION (see Figure E.3).

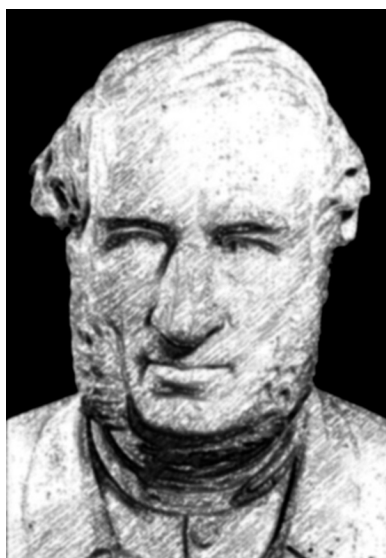


Figure E.3 Samuel Earnshaw (1805–1888).

Earnshaw's theorem

[computational, electromagnetism, general] A statement made by SAMUEL EARNSHAW (1805–1888) in 1839 on passive MAGNETIC LEVITATION. Based on his observations and calculations, he postulated that no stationary fixed configuration of magnets can be maintained in a stable equilibrium by any combination of static MAGNETIC FIELDS with resulting magnetic forces or respective combinations of GRAVITATIONAL FORCES. On a second interpretation in 1842, he also stated that an assembly of POINT CHARGES cannot solely be maintained in a stationary stable equilibrium resulting from the electrostatic interaction between the fixed and static charges alone. This lemma is a consequence of the GAUSS'S LAW, stating that the ELECTRIC FORCE (F_{electric}) resulting from an electric field (and equivalently for a MAGNETIC FIELD) will always be DIVERGENCELESS, meaning that there will be no local maxima or minima. The closest to a minimum/maximum result of the LAPLACE EQUATION for the electric potential will be SADDLE POINTS. $\nabla \cdot \vec{F}_{\text{electric}} = \nabla \cdot (-\nabla U) = -\nabla^2 U = 0$, where ∇U is the DIVERGENCE of the potential, and subsequently $\nabla^2 f = \nabla \cdot \nabla f = \Delta f = \sum_{i=1}^n \partial^2 f_i / \partial x_i^2$ is the LAPLACE OPERATOR (second-order differential operator in the n -dimensional [axis: x_i] EUCLIDEAN SPACE, generalized function f), and U is the electrical potential. This principle will apply to molecular configuration in the same manner as on a MACROSCOPIC scale.

Earth

[general] The Earth is the third PLANET migrating outward in the sequence of CELESTIAL BODIES orbiting around the SUN in what is known as our SOLAR SYSTEM. The Earth's surface has 29% landmass and the remaining 71% is water. *Note:* This ratio is changing with respect to the climatological conditions. During the last ice-age (which ended approximately 12,000 years ago) this ratio was probably 31:69 since at that time, the sea level was approximately 85 m lower compared to current day. The Earth has a structure that is formed around an internal core, which has two components: the inner core, which is solid, and the outer

core, which is LIQUID. The core is enclosed by the mantle which in turn is covered by the crust, on which we live. The crust is only approximately 100 km thick versus the full radius of 6380 km on average (oblong ellipsoidal, compressed at the POLES). The MAGNETIC POLES of the Earth are the result of the rotation of the iron-rich outer core. The exact magnetic pole orientation is not fixed and the NORTH and South Poles have switch orientation (geomagnetic reversal) at least a documented 51 times over the past 12 million years, as recorded by the rock-sediment magnetic orientation. The GEOGRAPHIC NORTH and South Poles are fixed by geographic definition. The Earth's magnetic core may flip between 100,000 and 1 million years, and the last time was an estimated 780,000 years ago; the process itself may take 1,000–10,000 years. Magma, which is expelled in volcanic eruptions, will turn to lava when it flows over our soil. The magma originated from a depth below the surface ranging from 200 to 10 km, but still not precisely known. The Earth has an ATMOSPHERE that is composed in a layered format. The five principal layers moving outward toward space are the TROPOSPHERE (0–12 km), STRATOSPHERE (12–50 km), MESOSPHERE (50–80 km), THERMOSPHERE (80–700 km), and the EXOSPHERE (>700 km). Note that the International Space Station is in orbit at approximately 350 km. The Earth has seven continents: Africa, Antarctica, Asia, Europe, North America, Oceania, and South America; note that the North Pole theoretically does not consist of any landmass and is only frozen water hence does not form a continent or not part of any continent. The Earth's population in 2014 is approximately 7.2 billion people. The 10 countries with the largest population, in decreasing rank are China, India, the United States, Brazil, Pakistan, Nigeria, Bangladesh, Russia, and Japan (see Figure E.4).

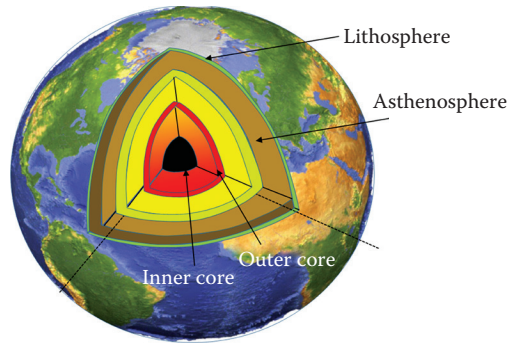


Figure E.4 Images representing various characteristics and properties of Earth.

Earth, angular momentum

[general] Looking down on the NORTH Pole from outer space will show that the EARTH is rotating counter-clockwise. The revolutions are very stable at an ANGULAR VELOCITY: $\omega = 7.27 \times 10^{-5} \text{ rad/s}$. For a solid sphere, the angular momentum is defined by the MOMENT OF INERTIA: $I_{\text{rev}} = \sum m_i r_i^2$, where m_i is the mass of each point in the volume of the sphere and r_i the radius of each respective mass segment in relation to the axis of rotation passing through the origin of the REFERENCE FRAME. For a SOLID SPHERE (Note: This is an approximation since the Earth is technically an ellipsoid [see EARTH, ASPHERICITY]) the moment of inertia is $I_{\text{revsolid sphere}} = \frac{2}{5} m R^2$, with m the mass of the sphere and R the radius at the equator. This yields for the angular momentum: $L_{\text{ang}} = I_{\text{rev}} \omega = (9.71 \times 10^{37} \text{ kgm}^2) \times (7.27 \times 10^{-5} \text{ rad/s}) = 7.06 \times 10^{33} \text{ kgm}^2/\text{s}$. However, the Earth also has PRECESSION and swings in a manner similar to a TOP. The precession provided the variation of the axis with respect to the SUN and hence the SEASONS.

Earth, as a conductor

[general] Generally a homogeneous solid CONDUCTOR will by definition be devoid of an electric field on the interior while all the charges are concentrated on the surface. As a result, inside a solid conductor the electric potential will be the same for the entire volume (i.e., equipotential). However, since the EARTH is not homogeneous, there will be potential differences across the surface of the Earth, although generally the connected solid surface is at the same potential and is assumed to be at zero potential, at least in reference to the power plants generating the ELECTRICITY to which we reference the Earth as “GROUND.” Inside the PLANET the LIQUID core itself generates electrical potential differences and both electric and magnetic fields are created. The MAGNETIC FIELD lines extend around the planet and are distorted by solar influences to yield the EARTH’S MAGNETIC FIELD.

Earth, asphericity

[astrophysics, general, geophysics] Even though SIR ISAAC NEWTON (1642–1727) showed that at any point outside the shell of the EARTH’S CRUST, all the mass can be considered in the center of the EARTH, the fact that the Earth is not a perfect sphere has its implications. Because of the rotational MOTION, the Earth is compressed at the POLES with the equator having an approximately 43 km larger diameter than the pole to pole DISTANCE. Apart from the valleys and mountains, the NORTH Pole jets out over a significant surface area producing an Earth shape reminiscent of a short pear (see Figure E.5).

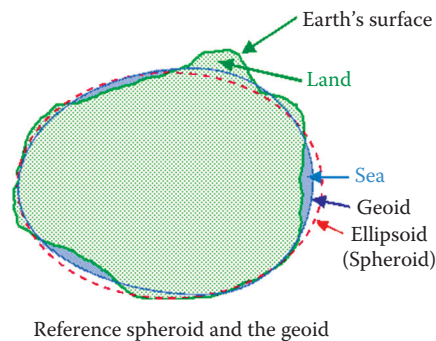


Figure E.5 Earth’s asphericity.

Earth, charge stored

[general] The only free moving charge that can reliably be stored is the electron, with an ELECTRIC CHARGE of -1.6×10^{-19} C. The EARTH in general stores a charge of approximately $-400,000$ C. Additionally, the Earth (on a clear day) also continuously leaks electrons to the ATMOSPHERE at a steady pace of 1500 C/s, while during a LIGHTNING storm these electrons are returned in quantities on average of 20 C per lightning bolt.

Earth, composition of atmosphere

[general] The ATMOSPHERE is composed of the following substances: 78% nitrogen, 21% oxygen, ~4.0% water VAPOR, 0.9% argon, 0.03% carbon dioxide, and TRACE gases, including neon, helium, krypton, and xenon (see Figure E.6).

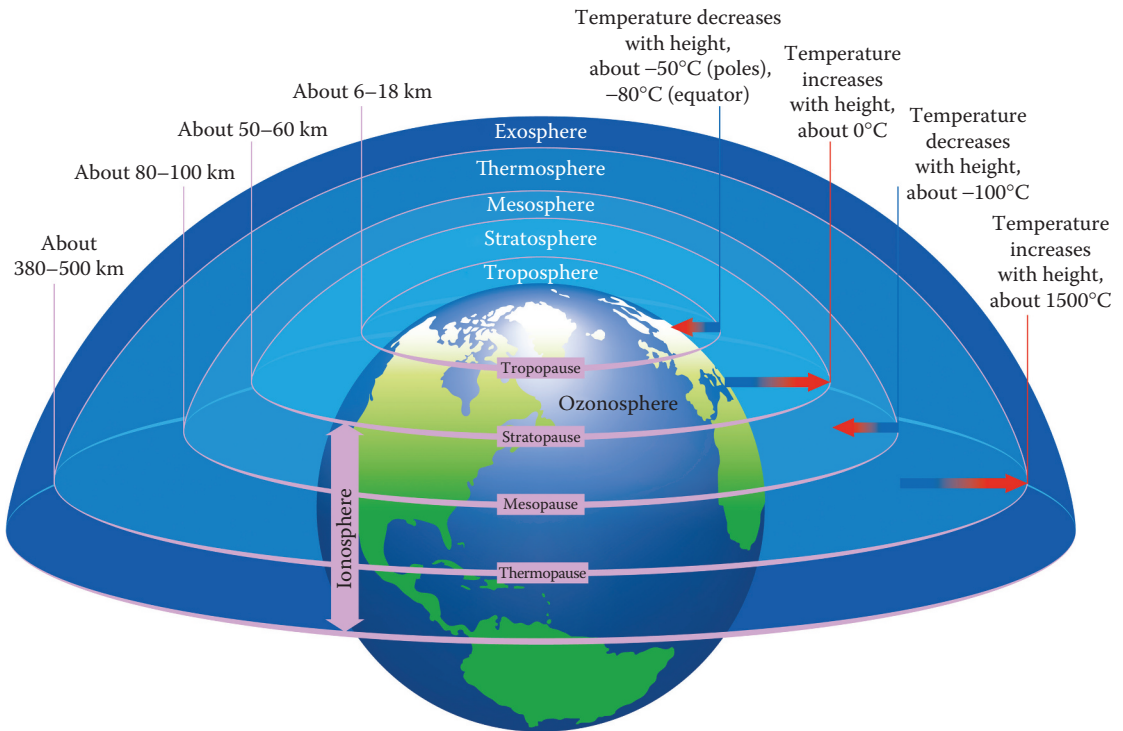


Figure E.6 Artist impression of the composition of the Earth's atmosphere.

Earth, density

[general] LORD HENRY CAVENDISH (1731–1810) concluded that the average density of EARTH based on spherical volume and the mass based on solar and lunar attraction should be $5.5 \times 10^3 \text{ kg/m}^3$, more than five times denser than water at $1.0 \times 10^3 \text{ kg/m}^3$.

Earth, gravitational interaction with objects

[geophysics, mechanics] As defined in NEWTON'S SECOND LAW, the attraction between the EARTH and external objects results in a force (F) that is proportional with the mass of the object (m) and the Earth's GRAVITATIONAL ACCELERATION ($a = g = 9.8 \text{ m/s}^2$) expressed as: $\vec{F} = m\vec{a}$.

Earth, gyroscopic stability

[general, geophysics, mechanics] The rotation of the EARTH with associated angular momentum creates a relatively stable orbit around the SUN, with a PRECESSION effect, equivalent to a spinning top. However, the MOON with its gravitational interaction creates an external force that influence the ENERGY CONSERVATION principle and disturbance of the CONSERVATION OF ANGULAR MOMENTUM. The Earth's rotational periodicity is increased by $2.5 \times 10^{-8} \text{ s/day}$, which will result in an increase of the current 24 h day by approximately 3 h over 10^9 years.

Earth, heat flow

[computational, geophysics, thermodynamics] During the day, the EARTH is generally heated by the SUN and during the night, the Earth will locally experience radiative cooling. The thermal process in the top layer of the EARTH'S CRUST satisfies the heat equation for diffusive heating and cooling. Because of the large radius, the Earth's surface may be considered flat, which reduced the radiative heat DIFFUSION to a one-dimensional process: $(\partial\theta/\partial t) - (C/\rho)(\partial^2\theta/\partial z^2) = 0$, where θ is the temperature, t is time, C is a material constant, C is the SPECIFIC HEAT of the soil (or water for that MATTER), ρ is the local density (averaged in this case), and z is the depth. The heat flow (Q) per unit time out of a surface with area A is defined as $(dQ/dt) = \int_{z_1}^{z_2} \rho C (\partial\theta/\partial t) dz A$. One major boundary condition that holds true for the globe is that one side of the medium is kept at a constant temperature (inner Earth). This is the DIRICHLET BOUNDARY CONDITION, in contrast to when heat is syphoned off, where the NEUMANN BOUNDARY CONDITION applies. The SOLUTION of the DIFFUSION EQUATION uses the Sturm–Liouville eigenvalues yielding a solution of the form: $\theta(x,t) = \sum_{n=1}^{\infty} C_n e^{-n^2\pi^2 kt/L} \sin(n\pi z/L)$, where n is the series counter for the harmonics, L is the characteristic length, and $k = C/\rho$. Note $\pi z/L = \omega t$ with ω the ANGULAR VELOCITY and t time. The AMPLITUDE of the n th harmonic of the fluctuations decreases exponentially with increasing depth, and hence the influence of the subsequent harmonics will be less or even negligible. Because of the dampening only the first harmonic is transferred to depths greater than half the penetration of the first harmonic. Based on the first-order approximation an indication of the depth at which temperature changes are still noticeable can be made. For DIURNAL (day-night) temperature fluctuations, the depth at which there is less than 1 °K variation on average (depending on location, e.g., city vs. desert), the temperature will be at thermal equilibrium at depths greater than 1 m, whereas the annual fluctuations are not statistically significant at depths greater than 10 m, taking the local climatological conditions into account for corrections. In general, the temperature fluctuations at depths less than the equilibrium depth are out of PHASE by one half period, whereas closer to the surface the HYSTERESIS will be lesser with decreasing depth. Because of the DAMPING effect with factor $\text{EXP}(-\sqrt{\omega/2k} x)$ with value $\sqrt{\omega/2k} \cong 2\pi/900 \text{ cm}^{-1}$, for seasonal variations the period is $T = 365 \times 24 \times 3600 = 31,536,000 \text{ s}$ for ordinary soil $k = 2 \times 10^{-7} \text{ m}^2/\text{s}$ yields a depth of roughly 4.50 m at which a change in phase of π will occur. At this depth, the HEAT TRANSFER will experience a delay of $T/2 = 6$ months. At this point, the damping factor is approximately $e^{-\pi} \cong 1/16$. On a daily fluctuation, this results in damping and PHASE ROTATION at 1.23 m for the values above (see Figure E.7).

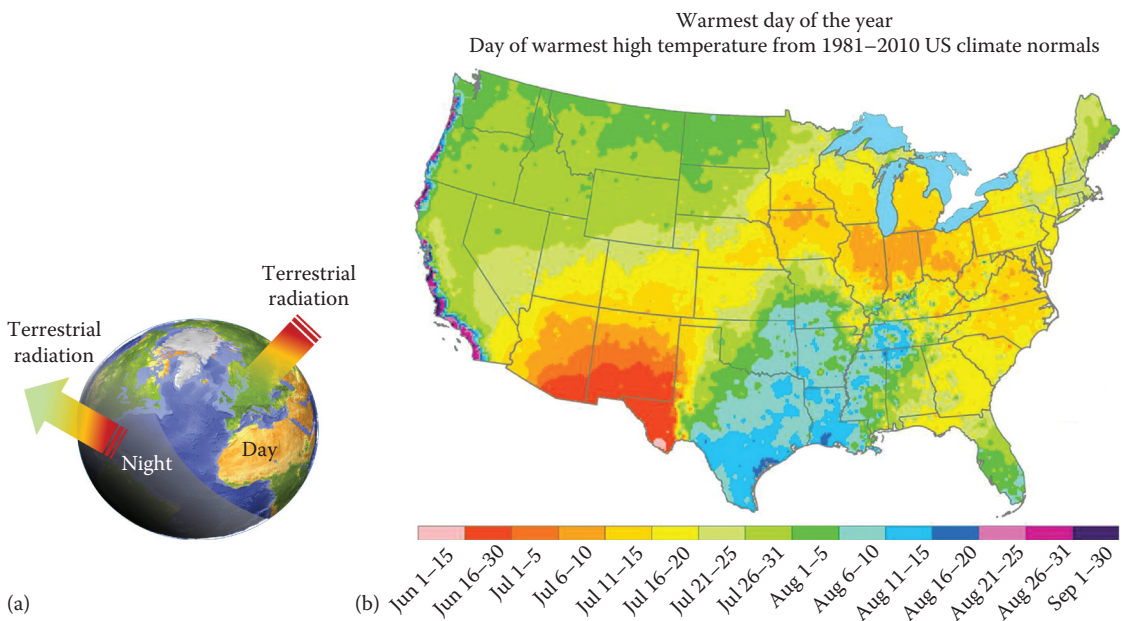
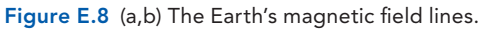


Figure E.7 (a) Global temperature profile and (b) heat flow. (From National Oceanic and Atmospheric Administration, United States Department of Commerce; Silver Spring, MD, USA.)

E

[general] The EARTH performs a full rotation around the SUN in approximately 365 days and 5 h, more exact: $T = 31,554,000$ s, which converts into ANGULAR VELOCITY of $\omega = 2\pi/31,554,000 = 1.9912484 \times 10^{-7}$ rad/s, whereas for the daily rotation around it own axis the angular velocity is $\omega = 2\pi/24 \times 3600 = 7.2722 \times 10^{-5}$ rad/s.



Earth, rotation

Earth satellite

[general] Satellites are used for various data transmittance purposes: television and RADIO communications and observation. Satellites are moving around the EARTH in various distinctly different motions. Certain satellites are placed in a fixed location with respect to the Earth's geometry, so that we do not have to adjust the (dish-) ANTENNA aimed at the SATELLITE used for television reception. The fixed location with respect to Earth refers to the fact that the satellite is in the GEOSYNCHRONOUS ORBIT or GEOSTATIONARY ORBIT. Spy satellites and weather satellites, on the other hand, are moving around in variable or predetermined patterns, scanning the surface in a grid-pattern. Other forms of orbital MOTION are equatorial orbit, graveyard orbit, low Earth orbit, medium Earth orbit, MOLNIYA ORBIT, polar orbit, subsynchronous orbit, and supersynchronous orbit (see Figure E.9).

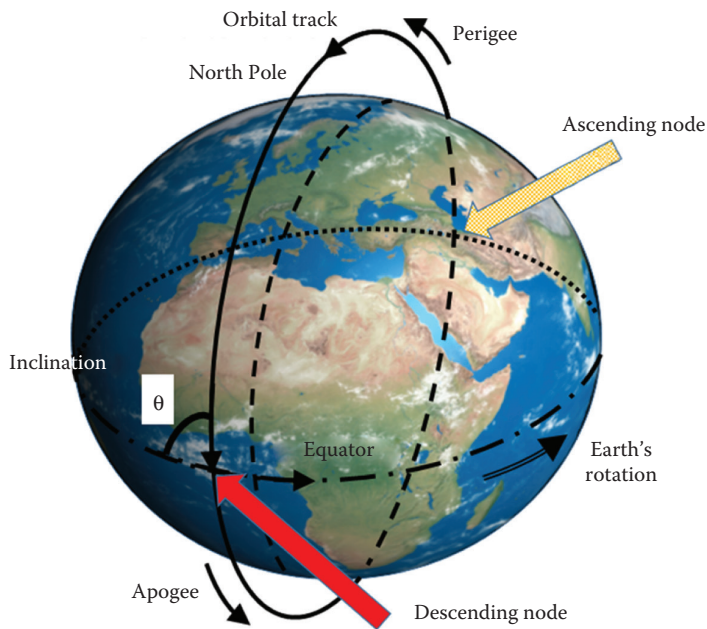


Figure E.9 Pattern of the orbit and position for satellites in orbit around the Earth.

Earthquake

[computational, fluid dynamics, geophysics, thermodynamics] It primarily means the sifting of the TECTONIC PLATES because of the continuous MOTION of the Earth's shell, however slow. The WAVE action associated with the motion of the shell is subject to DISPERSION due to the inhomogeneous composition of the mantle, specifically the LIQUID filled lithosphere (e.g., marked by volcanic eruptions). The inharmonic motion of the tectonic plates causes clashes, providing a SHOCK WAVE that propagates along the crust. The long-term slow movement of the tectonic plates is also visible in the ever-increasing transatlantic separation between Africa and South America, which at one time seem to have been joined together based on their respective coastal contour shapes. The existence of faults was first suggested by the Japanese scientist and geologist Bunjiro Koto (1856–1935) in 1891, after studying the Japanese earthquake of 1871. Bunjiro Koto may be recognized as the first seismologist, specifically with his appointment in 1893. The Koto model was refined by the study of the 1906 San Francisco earthquake by geologist Henry Reid from the United States. Harry

Fielding Reid (1859–1944) provided a shear strain model in the shell based on the continual tectonic movement in 1911 (see [Figure E.10](#)).

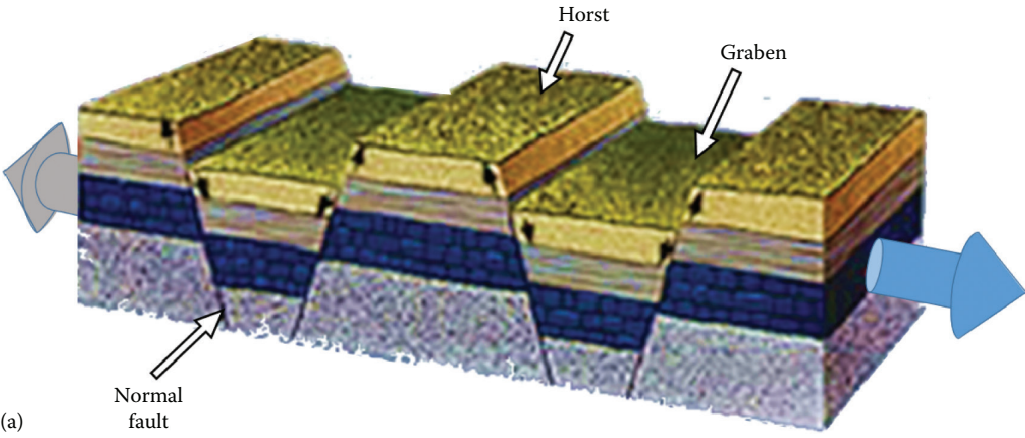
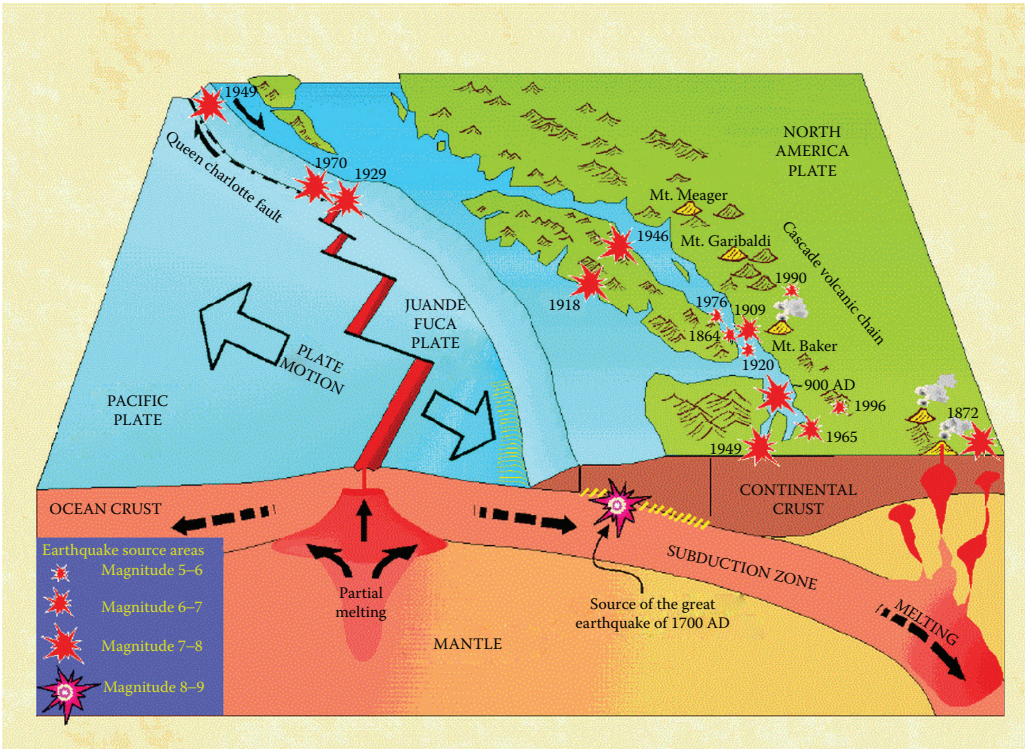


Figure E.10 Earthquake: (a) Vancouver, Canada. (Courtesy of The Canadian Geoscience Education Network (CGEN) is the education arm of the Canadian Federation of Earth Science; Ottawa, ON, Canada.) (Continued)

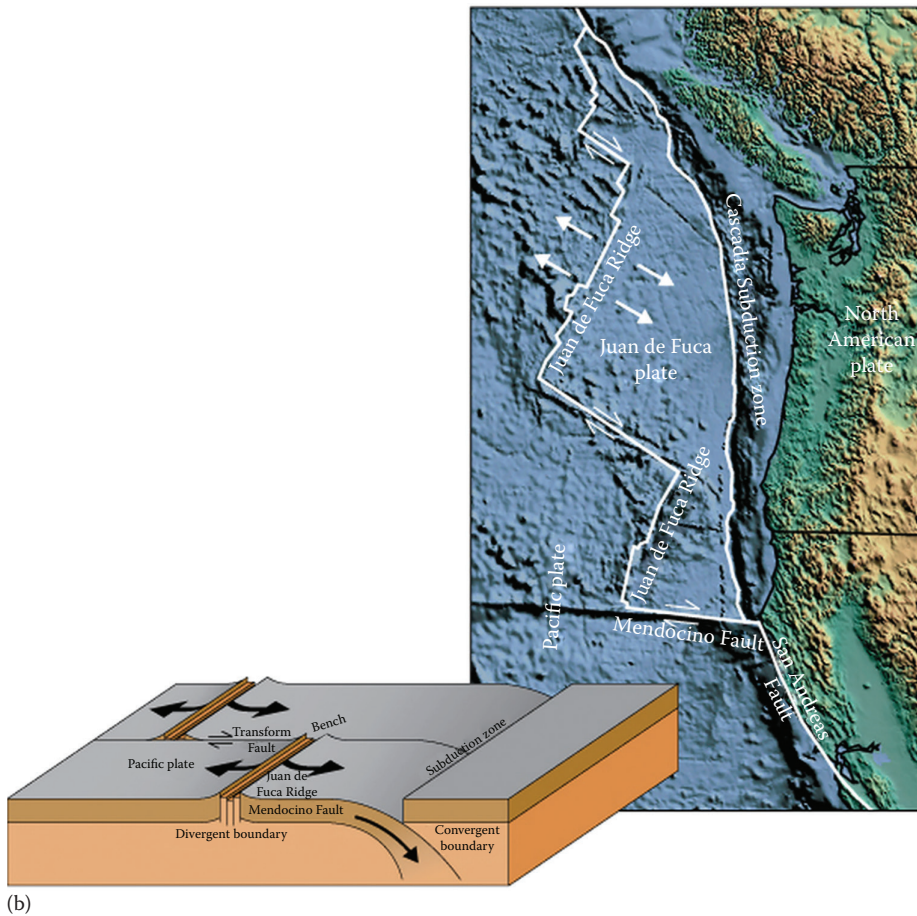


Figure E.10 (Continued) Earthquake: (b) earthquake crack after tremor in northern California. (Courtesy of Incorporated Research Institutions for Seismology, iris.edu.)

Earthquake compression wave

[general] The compression waves associated with an EARTHQUAKE are longitudinal waves. Earthquake compression waves are also called “primary waves” or “P-waves.” The primary waves are preceding the secondary or S-waves. Earthquake compression waves are more pronounced resulting from underground nuclear explosions or weapons testing and allow for a mechanism to distinguish “man-made” from natural earthquakes. The bulk-modulus partially define the propagation is defined as $B_{\text{elastic}} = -[\Delta P/(\Delta V/V_0)]$, where ΔP represents the pressure gradient, ΔV the EXPANSION/contraction of an undisturbed volume V_0 . The bulk-modulus is most likely a function of depth, due to the changes in density and deformability with DISTANCE to the surface and soil composition as a function of depth. The disparity in the bulk modulus will result in a DISPERSION in wave-propagation because the propagation speed is directly proportional to the bulk modulus and DENSITY (ρ) as $v = \sqrt{B_{\text{elastic}}/\rho}$; note that generally the speed of propagation of the compression still increases with increasing density due to the compounding factors affecting the bulk modulus as well. This phenomenon will be different for an earthquake-induced TSUNAMI, where $v = \sqrt{Y_{\text{elastic}}/\rho}$, where $Y_{\text{elastic}} = \text{stress/strain} = \sigma_{\text{stress}}/\epsilon_{\text{strain}}$ represents the Young’s modulus of the LIQUID, with $\sigma_{\text{stress}} = F/A$,

the force tangential to a unit surface area and $\epsilon_{\text{strain}} = \Delta L / L_0$ with L_0 the undisturbed length and ΔL the deformation in length under the influence of an applied force (see Figure E.11).

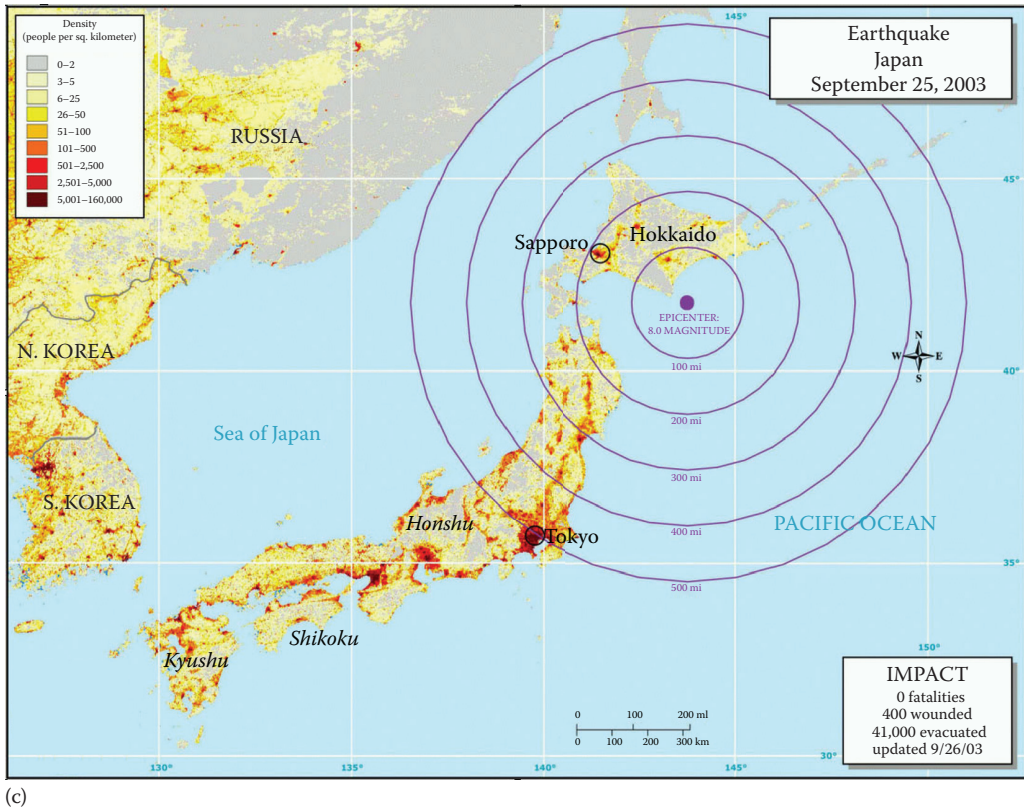
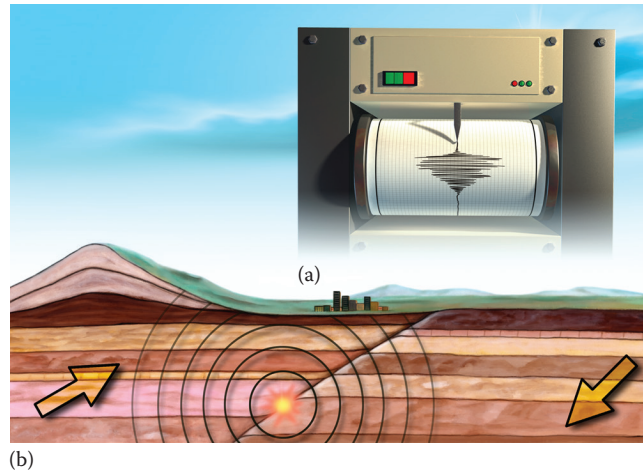


Figure E.11 (a) Graphical illustration of earthquake compression wave with seismic recording (Courtesy of USAID Office for Foreign Disaster Assistance.), (b) displacement diagram at a fault line, and (c) epicenter illustration for the radiating compression wave that represents the 2003 earthquake in Japan with magnitude 7.3 on the Richter scale, named after Charles Richter (1900–1985).

Earth's crust

[general, geophysics, nuclear] The EARTH can be thought of as being divided in four separate layers, or concentric shells. The outer part is the crust, upon what we live, with a thickness of 1–100 km. Below the crust is the mantle. The mantle can be subdivided in upper and lower mantle. The crust and the upper part of the mantle are also called the “lithosphere.” Below the mantle is the inner core. The semi-rigid part of the mantle that supports the magma FLOW is called the “ASTHENOSPHERE.” Inside the outer core is the inner core. The asthenosphere provides the mechanism for the movement of TECTONIC PLATES, that is, earthquakes. Most of our knowledge is from experimental observations of the crust. All other information from the inner portions is based on mathematical derivations as well as speculation. Based on various observations, it has been derived that the inner core must have temperatures and associated pressures that are so great that the constituents such as metals are squeezed together preventing movement as a liquid. The components in the inner core presumably vibrate in place as if it was a solid (see Figure E.12).

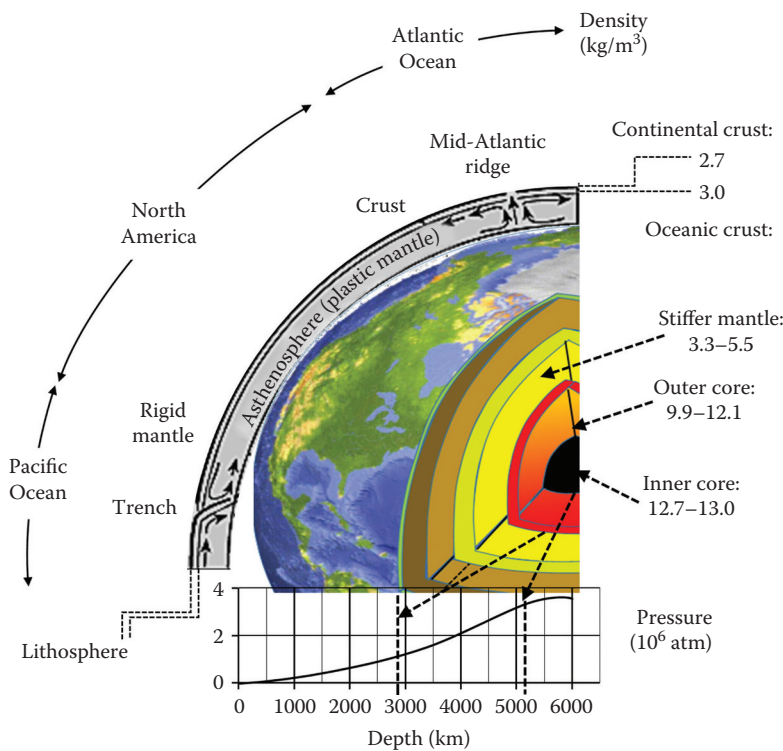


Figure E.12 Diagram of composition of the Earth's crust.

Eccles, John Carew (1903–1997)

[biomedical, electromagnetism] An Australian physiologist and scientist that worked on a formal description of the SYNAPTIC communication and encoding for NERVE CELLS and received the Nobel Prize in Physiology in 1963 together with SIR ANDREW FIELDING HUXLEY (1917–2012) and SIR ALAN LLOYD HODGKIN (1914–1998), where the latter two described the ACTION POTENTIAL in a nerve CELL (see [Figure E.13](#)).



Figure E.13 John Carew Eccles (1903–1997). (Courtesy of The John Curtin School of Medical Research, The Australian National University, Canberra City, Australia.)

Echogenic

[biomedical, imaging, solid-state] Material property referring to the ability to “reflect” acoustic pressure WAVE at an interface between two media. In biomedical imaging, soft tissue (e.g., fat and MUSCLE) is less echogenic than the abdomen, the HEART in the lung and bone. Teeth are too hard to support any imaging of the internal structure by ultrasonic means. Specific attention is given to the fetus in the womb, which is established primarily and more pronounced in the second trimester of fetal development (*also see* ULTRASOUND).

Echolocation

[biomedical, imaging] The use of SOUND to determine the DISTANCE between the source and a discontinuity in acoustic impedance. Several animals use sonar echolocation for orientation, for instance, bats and porpoises. Humans use sonar for echolocation for underwater navigations, especially by submarines, but also by blind people using specially designed sonar walking stick, next to the tried-and-true method of tapping with a regular METAL or wooden stick. Additional applications are in the sonographic location of fish and in ULTRASONIC IMAGING. Bats employ frequency modulation to increase the RESOLUTION and obtain superior signal-to-noise ratio. Porpoises (e.g., dolphins) produce ultrasonic waves in the range of several hundred kilohertz with the specially designed resonant organs just inside their blow-hole, which is subsequently emanated from the acoustic “magnaphone” in the bulge on their forehead. Bats use vocal cords in their throat. Both bats and porpoises emit the sound in short burst in the order of millisecond duration, at variable rate of emission. The emission can be composed of a well-defined FREQUENCY SPECTRUM, specifically pertaining to the frequency modulation aspect. The frequency spectrum will change under REFLECTION and hence reveal details to the BAT about the mechanical properties of the object: biological or inanimate, based on, for instance, the Young’s modulus and surface characteristics. Certain bats also have the ability to send out constant frequency sound burst for which they are able to distinguish the DOPPLER shift and hence derive their relative

speed with respect to prey and obstructions. Bats are known to utilize a low AMPLITUDE general scanning mode, which increases in frequency spectrum and amplitude once a target (prey) has initially been identified (see [Figure E.14](#)).

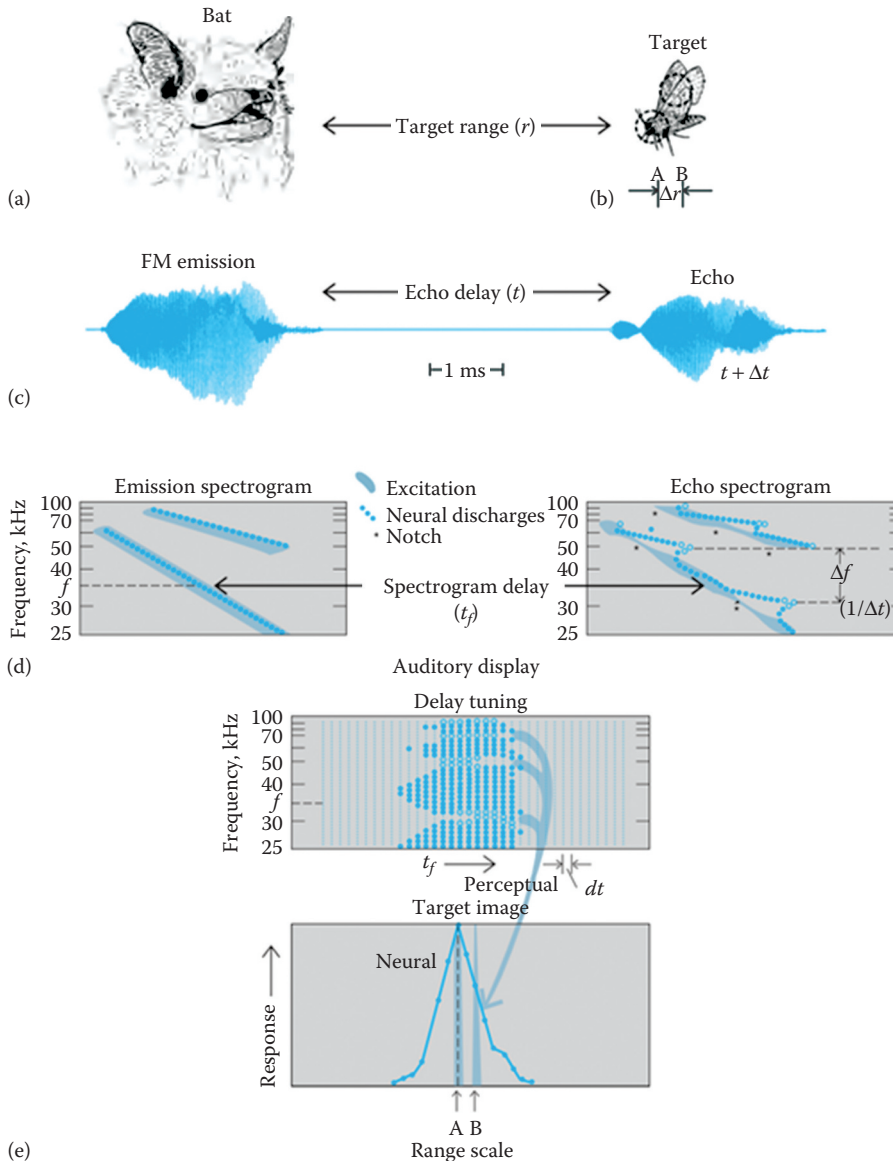


Figure E.14 (a) The bat emits a sonar sound that travels outward to impinge on an insect at some target range (r). Reflections return to the bat from various insect body parts—for example, wing and head separated by a small difference in range (Δr). These sources of reflections are called “glints,” and the insect is depicted here as a 2-glint target. (b) Sound-pressure waveforms of the bat’s transmitted sonar sound and the reflections from the insect’s glints—wing and head. The transmitted sound is heard directly by the bat to initiate processing by establishing a zero-time origin for reception of subsequent echoes (long vertical dashed line across pictures). Echoes return to the bat’s ears after a delay (t) related to target range (r) at rate of 5.8 ms/m. Reflections from the 1st and 2nd glints add together at a small time separation (Δt) to interfere with each other when they form a combined echo arriving at the bat’s ears. For each transmitted sound, the acoustic stimulus received by the bat is not just the echo but a “pair” of sounds—the outgoing broadcast received directly at the moment of emission followed by the returning combined echo composed of, however, many reflections returned by the target’s glints. (c) Spectrograms—or time-frequency plots—of the transmitted sound (left) and combined echo (right) showing the frequency modulated (FM) sweeps. The broadcast signal contains two sweeps—a first harmonic from 45 to 22 kHz and a second harmonic from 80 to 45 kHz—that appear as sloping ridges, one over the other. (Continued)

Figure E.14 (Continued) The echo also contains these two harmonics, but the sloping ridges for the combined echo spectrogram are not as smooth as those in the broadcast spectrogram because interference between the overlapping reflections from the 1st and 2nd glints creates alternating peaks (p) and notches (n) that appear as ripples or undulations. The notches are locations where energy in the echo has been canceled by interference; their locations are the principal defining characteristics of the ripples because their frequencies (f_1 , f_2 , and f_3) are related to the delay separation (Δt) of the reflections from the glints (see Figure E.2a). The bat's inner ear transforms the spectrograms of broadcasts and echoes into neural spectrograms composed of spikes that register the FM sweeps in terms of the tuned frequencies of different neurons and times, or latencies, of the spikes (see Figure E.9). (d) Diagram illustrating neural spectrograms of a broadcast and echo. The spectrogram is composed of on-responses in neurons tuned to different frequencies (vertical axis). For downward FM sweeps (as in c), excitation in the bat's inner ear moves rapidly from high frequency (basal end of cochlear spiral) to low frequency (apical end of cochlear spiral). As this excitation rushes past receptors, it triggers spikes (red circles) in auditory nerve fibers from any given location (see Figure E.3a and b). (Conventional spectrograms from Figure E.1c are shown here as shades of gray.) The on-response (first spike) is sharply coincident with the onset of this rapidly moving excitation, and it registers the time of occurrence of the neuron's tuned frequency in each sweep. At any given frequency, the total duration of excitation is very brief—only a few hundred microseconds in duration—because the sound sweeps rapidly away to lower frequencies. Consequently, there is only time enough for the on-responses to occur reliably. The whole volley of on-response spikes (red circles) spread across neurons tuned to different frequencies traces the shape of the FM sweep for the broadcast and then for the echo. In the auditory nerve, if excitation is strong, cells often produce one or more additional spikes that follow the on-response, but they are less sharply synchronized to the onset of excitation, and cells exhibit spontaneous activity, too, that has no relation to stimuli. These secondary spikes are stripped out of the volley as the spikes pass through the cochlear nucleus, so that only the on-responses shown here are used to determine echo delay. Note that the frequency tuning of the neurons segregates the traces for the first and second harmonic sweeps in each sound. Because the echo contains closely spaced reflections of the broadcast that were returned from different parts of the target (Figure E.1a), interference occurs, and some frequencies are canceled out to create notches in the spectrogram. Auditory neurons tuned to frequencies of notches fail to produce on-responses, so there are gaps or "holes" (unfilled circles around f_1 , f_2 , and f_3) in the neural spectrogram for the echo. In auditory nerve fibers, generation of spikes takes place on the neurons at a site very close to the organ of Corti (Figure E.3b), and the spikes have a latency of about half a millisecond. The proximity of the spike-generation site to the receptors, and the proximity of the bat's cochlea to its brainstem (see Figure E.3a and d) may make spike initiation particularly stable in time and minimize the distance spikes have to travel to reach the first synapse, where synchrony of spikes across closely spaced auditory-nerve fibers is used to sharpen temporal registration of the spectrogram before it is distributed upward throughout the auditory pathway for further processing. (e) Hypothetical traces depicting two possible versions of the image of echo delay perceived by the bat to represent target range. The horizontal axis (r) is a psychological scale showing the perceived value of delay. Although this now refers to events inside the bat, such values nevertheless can be measured in behavioral experiments. The two possible versions of the image differ according to how information in the spectrograms is used to estimate range from delay. Does the bat perceive an "image" corresponding to the delay of the echo spectrogram representing the overall range (r) to the target, shown here as a blue distribution for the combined echo as a whole? In this case, the underlying representation is a single numerical delay estimate with a potentially broad time-delay corresponding to the integration time (t_i) of the spectrogram (see c). Both glints are subsumed into one delay or range perception. Or, does the bat separately perceive the glints themselves (first glint dark blue; second glint red), even though they are separated by a small interval of distance (Δr), so that their reflections are separated by an equivalently small amount of time (Δt) compared to the integration time (t_i)? If the bat perceives the first kind of image, then target range (r) most likely is estimated from the auditory equivalent of rightward displacement of the spectrogram of the transmitted sound until it superimposes on the spectrogram of the echo. Although the range difference between the glints (Δr) is not itself perceived as such, the presence of interference notches in the echo provides the bat with indirect information about the target's structure. However, if the bat perceives the second kind of image, in which the two glints are recognized as being at different ranges, then the means by which the bat determines the delays of the reflections must be different for the two glints because their manifestation in the combined echo spectrogram (c) is different. First, the overall delay of the combined echo most likely is estimated from the auditory equivalent of rightward displacement of the spectrogram of the transmitted sound to determine the overall range (r). Second, the delay separation of the reflections from the two glints most likely is estimated from the frequencies of the interference notches in the combined spectrogram to determine the range separation (Δr). Note that this latter procedure explicitly involves transforming numerical values of frequency (for notches) into an equivalent numerical value of time (for delay separation), that is, inverse Fourier transform.

Eckert, Ernst Rudolf Georg (1904–2004)

[fluid dynamics] An aeronautical engineer and physicist from the Czech Republic (erstwhile Czechoslovakia). Ernst Eckert worked on film-coating, specifically with respect to durability and efficiency related issue in aeronautical engines. Dr. Eckert may be considered one of the fathers of modern practical HEAT TRANSFER and mass transfer. His contributions are personified by the ECKERT NUMBER (see Figure E.15).



Figure E.15 Ernst Rudolf Georg Eckert (1904–2004). (Courtesy of George Grantham Bain Collection, New York City; United States Library of Congress, Washington, DC.)

Eckert number ($Ec = v^2 / [c_p(T_s - T_\infty)]$)

[fluid dynamics] A dimensionless number applicable to compressible FLOW and the phenomena of HEAT TRANSFER as well as momentum transfer. It has been named in honor of the principal contributor ERNST RUDOLF GEORG ECKERT (1904–2004). The relative ratio of the kinetic energy, marked by the VELOCITY (v) squared, with respect to the enthalpy (H) difference at the WALL. The heat transfer in a system is equal to the enthalpy change in the system: $\Delta H = \Delta Q$. The difference in enthalpy is between the main body of flow temperature (T_∞) and the surface temperature (T_s), with c_p being the SPECIFIC HEAT.

Eddington, Arthur Stanley, Sir (1882–1944)

[astronomy/astrophysics, general] An astronomer, physicist, and mathematician from Great Britain. Sir Arthur Eddington is most known for his contributions to the brightness of celestial objects (i.e., stars) with respect to the anticipated core and surface temperature (see [Figure E.16](#)).



Figure E.16 Sir Arthur Stanley Eddington (1882–1944). (Courtesy of United States Library of Congress, Washington, DC.)

Eddington limit

[astrophysics, general] The maximum luminosity (radiance: L_{Edd}) a celestial body (i.e., specifically geared to the emissions of the QUASAR star, discovered in 1963) can attain based on an energy balance resulting from the RADIATION FORCE acting outward and the gravitational force acting toward the core: $L_{\text{Edd}} = 3.0 \times 10^4 (m_{\text{quasar}}/M_{\odot})$, where $M_{\odot}$ is the mass of the STAR, $L_{\odot}$ the radiance of the Earth's SUN, and m_{quasar} the mass of the quasar. It is named after the astronomer SIR ARTHUR STANLEY EDDINGTON (1882–1944), also referred to as the “Eddington luminosity.”

Eddy current

[electromagnetism, fluid dynamics, general] Circular current in either electrical CONDUCTOR or liquids. On electric scale, the eddy refers to a system of CIRCULATION current on a MICROSCOPIC scale inside a conductor. Eddy-current loops will generate MAGNETIC FIELD as described by the BIOT–SAVART LAW, and when these magnetic moments line up the object itself forms a PERMANENT MAGNET (*also* FOUCAULT CURRENT). Eddying water currents refer to circular currents in large water bodies. The eddy is associated with VORTEX or maelstrom (whirlpool) formation. Maelstroms are named, just as hurricane and typhoons.

Edison, Thomas Alva (1847–1931)

[general] A scientist and inventor from the United States. Thomas Edison is well known for his introduction of the incandescent light bulb in 1880. In 1877, Edison invented the phonograph, a mechanical SOUND recording and replay device, the predecessor to the record player in the twentieth century, playing vinyl records. Additional efforts were on the perfection of the telephone introduced by his contemporary ALEXANDER GRAHAM BELL (1847–1922) (see [Figure E.17](#)).

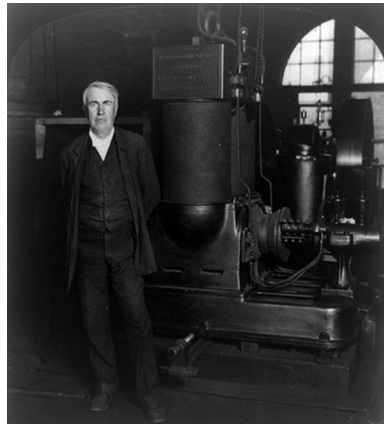


Figure E.17 Thomas Alva Edison (1847–1931); Thomas Edison and his original dynamo, Edison Works, Orange, NJ, c. 1906. (Courtesy of the United States Library of Congress, Washington, DC.)

Edison effect

[atomic, nuclear] The fact that charged particles (later identified as electron) are emitted from a heated filament will migrate in VACUUM to a (grounded or positively charged) METAL plate and hence create a free-space current. This phenomenon introduced the concept of the ELECTRON TUBE. The thermal emission of electrons is governed by the work function of the material. The thermionic emitter current density ($J = I/S$, where S is the emitter surface area) was described in 1923 by SAUL DUSHMAN (1883–1954) as $J = I/S = A_0 T^2 \text{EXP}[-b_0/T]$, where $A_0 = 60.2 \times 10^{-4}$ Amps / $\text{m}^2 \text{C}^2$, while $b_0 = e(E_w/k)$ (where E_w is the WORKFUNCTION of the medium, $k = 1.3806503 \times 10^{-23}$ $\text{m}^2 \text{kg} / \text{s}^2 / \text{K}^{-1}$ the Boltzmann constant, and $e = 1.60217646 \times 10^{-19}$ C an electron charge) is a material constant, as a MATTER of fact, it is an indication of the energy requirement to get the electrons through the surface, or in thermodynamic terminology, this can be interpreted as the LATENT HEAT OF EVAPORATION of the electrons for the material in question. The work of Dushman was based on the THIRD LAW OF THERMODYNAMICS.

Ehrenfest, Paul (1880–1933)

[atomic, general, nuclear, quantum, thermodynamics] A scientist and mathematician from Austria. Ehrenfest's contributions were in the field of theory of adiabatic invariants, PHASE transitions, and general THERMODYNAMICS (see [Figure E.18](#)).



Figure E.18 Paul Ehrenfest (1880–1933), with his graduate students at the University of Leiden, the Netherlands; 1926: Gerhard Heinrich Dieke, Samuel Abraham Goudsmit, Jan Tinbergen, Ralph Kronig, and Enrico Fermi.

Ehrenfest relation

[thermodynamics] The “birth–death–rate” process for SECOND-ORDER PHASE TRANSITION with respect to the number of particles (measured as partial pressure P) involved between phases I and II, occupying a volume V , with respective entropies S_I and S_{II} as a function of temperature (T), expressed as $dP/dT = \{(\partial S_{II}/\partial T)_P - (\partial S_I/\partial T)_P\} / \{(\partial S_{II}/\partial P)_T - (\partial S_I/\partial P)_T\} = \Delta c_p / \Delta \alpha_T TV$, and $dP/dT = \{(\partial V_{II}/\partial T)_P - (\partial V_I/\partial T)_P\} / \{(\partial V_{II}/\partial P)_T - (\partial V_I/\partial P)_T\} = \Delta \alpha_T / \Delta \kappa_T$, with α_T being the THERMAL EXPANSION coefficient, c_p the SPECIFIC HEAT at constant pressure, and κ_T the adiabatic bulk modulus. It is also known as the “Ehrenfest model,” based on the work by PAUL EHRENFEST (1880–1933).

E

Eigenfunction

[atomic, computational, nuclear, quantum] A particular SOLUTION to a complex differential formulation that represent a characteristic function or value (i.e., EIGENVALUE) that can be used independently. The concept of eigenfunction originates from the use of “function space” or “Hilbert space.” The eigenfunction generally represents a particular function that is directly linked to the LINEAR OPERATOR. Eigenfunctions are widely used in solving the SCHRÖDINGER EQUATION. The eigenfunction is a solution to the operator (e.g., differential operator F_{op}) for every point where the operator is defined, which gives it the eigenfunction property. In the Schrödinger equation, for example, $F_{op}\Psi = f\Psi$, the function Ψ represents the eigenfunction and f is the eigenvalue belonging to the eigenfunction and the operator applied to the function (*also see* EIGENVALUE).

Eigenvalue

[atomic, computational, nuclear, quantum] Linear projects of a vector space, associated with a function on itself, will provide a linear transformation. The projections of the points that form the line that passes through the origin provide the unique and characteristic values of universal applicability referred to as “eigenvalues.” In a linear transformation of linear vector space, there is a SCALAR that is a direct SOLUTION to the function (solution to the EIGENFUNCTION). All eigenvalues correspond to the complex solution of datapoints in vector space outlined as eigenvectors. The eigenvalue times the unit matrix subtracted from the eigenfunction forms a matrix that has no INVERSION. The operator yields the “expected” value for the eigenvalue, which is a sharp value, using the SCHRÖDINGER EQUATION in the following format: $F = \int \Psi^* F_{op} \Psi d\tau = \int \Psi^* f \Psi d\tau = f \int \Psi^* \Psi d\tau = f$. This ensures that the eigenvalue has a sharp value; the variance $((\Delta F)^2)$ will illustrate that the following is satisfied: $(\Delta F)^2 = \int \Psi^* (F_{op} - F)^2 \Psi d\tau = F^2 - F^2 = \int \Psi^* f \Psi d\tau - f^2 = 0$. For the Schrödinger equation in particular, this provides a series of solutions (n), specifically with respect to the energy (E) written as $H\Psi_n = E_n\Psi_n$, (H is the HAMILTONIAN OPERATOR) with respective eigenfunctions Ψ_n and eigenvalues E_n . In case two eigenfunctions have the same energy, in which case the solution is found to be energy degenerate: $E_n = E_m$. In certain situations, the eigenfunction of the Hamiltonian may simultaneously be solutions to other operators, for instance, the operator for one or more components of the angular momentum (*also see* EIGENFUNCTION).

Eigenvector

[atomic, nuclear] The linear transformations from the eigenfunctions to vector space that are outlined by the eigenvalues are transformed as eigenvectors.

Einstein, Albert (1879–1955)

[atomic, biomedical, general, nuclear] Albert Einstein used the QUANTUM THEORY model presented by MAXWELL KARL ERNST LUDWIG PLANCK (1857–1947) in 1900 to formulate the particle-wave duality of the PHOTON representing ELECTROMAGNETIC RADIATION as one of the fundamental building blocks of the theory of light, as presented in one of three publications released in 1905. The discrete energy content of the Planck model is represented by the PARTICLE aspect, in contrast to the continuous energy spectrum of the theories of ELECTRICITY and MAGNETISM by JAMES CLARK MAXWELL (1831–1879). Another article released

in 1905 by Einstein introduces his concept of the THEORY OF RELATIVITY. A third presentation made by Albert Einstein in 1905 is on statistical MECHANICS, building on the works of LUDWIG EDUARD BOLTZMANN (1844–1906) and JOSIAH WILLARD GIBBS (1839–1903), primarily focusing on the movement of molecules in a FLUID media (see Figure E.19).

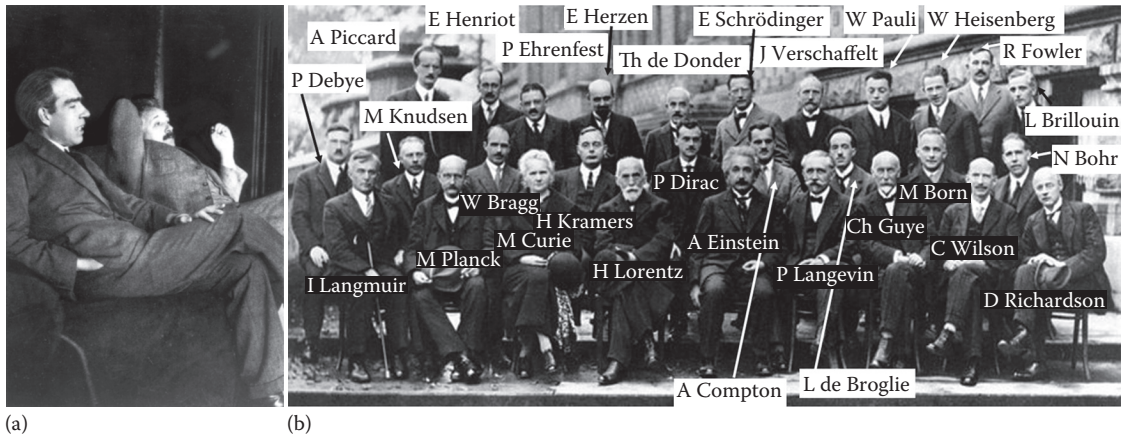


Figure E.19 (a) Albert Einstein (1879–1955) seated to the right of Niels Bohr (1885–1962; on Niels Bohr’s left hand side) during a conversation at the home of Paul Ehrenfest (1880–1933) in Leiden, the Netherlands in 1925. (b) The Solvay attendants in 1927 including Albert Einstein. The Solvay Conferences were originally organized by the industrialist Ernest Solvay (1838–1922) from Belgium and were generally held in Brussels, Belgium.

Einstein equations

[astrophysics, computational, relativistic] Analysis of the curvature of space and time based on the work by ALBERT EINSTEIN (1879–1955) performed between 1907 and 1915 and the interpretation and contributions from the mathematician from Russia, working in Germany. Hermann Minkowski (1864–1909) found to be a generalization of rotational invariance from space to “space-time.” Albert Einstein was a student of Hermann Minkowski. Hermann Minkowski defined four-dimensional space-time in theoretical format known as “Minkowski space-time.” The “curvature,” expressed by the Einstein tensor (G_{Einstein}) of space-time describing the relationship between the energy-momentum tensor (T_{em} ; QUANTIFICATION of the “matter content”) and GRAVITY expressed by the gravitational constant: G_{grav} under special relativistic conditions, with c the speed of light yields: $G_{\text{Einstein}} = (8\pi G_{\text{grav}}/c^4)T_{\text{em}}$, under general relativity this is written as $G_{\mu\nu} + \Lambda g_{\mu\nu} = (8\pi G_{\text{grav}}/c^4)T_{\mu\nu}$. Because of the multidimensional aspect, it is also known as “Einstein’s field equations.” The constant Λ is known as the “cosmological constant,” representing the value of the energy density of the VACUUM of space. After the discoveries by EDWIN POWELL HUBBLE (1889–1953) in 1929, the cosmological constant is generally assumed to be zero: $\Lambda = 0$. More generally, the space-time mathematics of general relativity is described as $G_{\text{Einstein}} = G_{\mu\nu} = R_{\mu\nu} - (1/2)R_{\text{curv}}g_{\mu\nu} + \Lambda g_{\mu\nu} = (8\pi G_{\text{grav}}/c^4)T_{\mu\nu}$, where $R_{\mu\nu}$ is the Ricci “curvature” TENSOR (mathematician from Italy Gregorio Ricci-Curbastro [1853–1925]), under the curvature SCALAR: $R_{\text{curv}} = g_{\mu\nu}R_{\mu\nu}$, where $g_{\mu\nu}$ represents the metric tensor. The Einstein tensor is symmetric in space-time: $G_{\text{Einstein}} = G_{\mu\nu} = G_{\nu\mu}$ and is DIVERGENCELESS: $\nabla_{\mu}G_{\mu\nu} = 0$. These gravitational equations can be used to solve the planetary orbital trajectories under a weak gravitational attraction, resembling NEWTONIAN MECHANICS (SIR ISAAC NEWTON [1642–1727]). The Ricci tensor can be related to the Riemann curvature tensor under a more generalized mathematical approach: $R_{\mu\nu} = R^{\alpha}_{\mu\alpha\nu}$, based on the work of. The geometric description between the point in space-time is generally described by the Riemann curvature tensor, after Georg Friedrich Bernhard Riemann (1826–1866), a mathematician from Germany. The notation for the space-time dimensional representation ($\mu\nu$) is derived from Christoffel symbols, based on the work of Elwin Bruno Christoffel (1829–1900), a mathematician from Prussia (Germany). The Christoffel symbols represent three-“dimensional” (not spatial dimension, but mathematical cube array of an n -dimensional

manifold: $n \times n \times n$) of real numbers, which describes, in mathematical space coordinates, the effects of parallel transportation over curved surfaces (see [Figure E.20](#)).

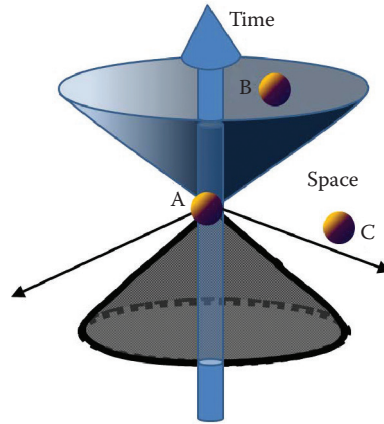


Figure E.20 Space–time convolution depicted as cones of time in a three-dimensional space.

Einstein–Lorentz transformation

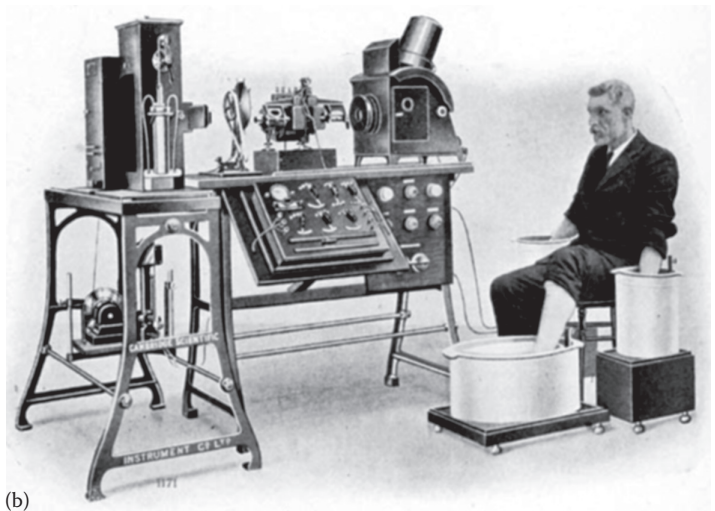
[atomic] Lorentz transformation applied to special and general relativistic phenomena (*see* **LORENTZ TRANSFORMATION**).

Einthoven, Willem (1860–1927)

[biomedical] A physiologist from the Netherlands who in 1903 developed the first device to record standardized three-point electrocardiograms from the DEPOLARIZATION vector progression for the HEART MUSCLE (ECK or EKG). Willem Einthoven received the Nobel Prize in MEDICINE for his work on the study of the mechanism of action of the heart and the data acquisition with subsequent SIGNAL processing aspects in 1924 (*see* [Figure E.21](#)).



(a)



(b)

Figure E.21 (a) Willem Einthoven (1860–1927) in 1906. (b) Einthoven with his arms and legs in the basins with electrically conducting solution acting as electrodes to record the electrocardiogram (ECG).

Ekman, Vagn Walfrid (1874–1954)

[fluid dynamics, geophysics] A geophysicist and oceanographer from Sweden. Ekman recognized the influence of Coriolis forces on the migration pattern for icebergs and corrected the movement trajectory which was initially based on the wind direction only. The MOTION is captured by the introduction of the Eckman layer (see [Figure E.22](#)).



Figure E.22 Vagn Walfrid Ekman (1874–1954).

Ekman layer

[computational, fluid dynamics] The FLUID layer underneath a floating object that balances the CORIOLIS FORCE influence on the MOTION, resulting from wind FLOW as well as pressure gradient $(\partial P / \partial x_i)$ forces in the water generated during flow next to turbulent DRAG. Generally, the theoretical analysis was based on the fact that the observed movement of an iceberg is at a 20° – 40° ANGLE in clockwise direction, with respect to the direction of the prevailing wind. The concept was introduced by VAGN WALFRID EKMAN (1874–1954) in 1902. The respective force balances are with respect to a flow with velocity $\vec{v} = (v_x, v_y)$ for a flow with diffuse eddy VISCOSITY $K_m = \xi'^2 \left| \partial v_x / \partial z \right|$, with ξ' the MIXING length and $\partial v_x / \partial z$ the vertical pressure gradient which is averaged, and where the Coriolis parameter is f_{Cor} , this yields for a fluid flow with density ρ_0 the following force densities: $-f_{Cor} v_y = (1/\rho_0)(\partial P / \partial x) + K_m (\partial^2 v_x / \partial z^2)$; $f_{Cor} v_x = (1/\rho_0)(\partial P / \partial y) + K_m (\partial^2 v_y / \partial z^2)$; and $(1/\rho_0)(\partial P / \partial z) = 0$, where x and y are parallel to the surface. Note that the diffuse eddy viscosity has been assumed as a constant, which is an approximation since the fluid density is not constant due to the inherent temperature gradient. The boundary conditions are as follows: $a(\partial v_x / \partial z)_{z=0} = \sigma_s^x = F / A_x$ is the shear stress in the x -direction at the surface resulting from the wind

and the ice field (with force F and affected area A) is $a(\partial v_y / \partial z)_{z=0} = \sigma_s^y$, where a is a material constant. The solutions to these conditions are the following:

$$v_x = v_{x0} + \sqrt{2} (fd)^{-1} \{ \sigma_s^x \cos((z/d) - (\pi/4)) - \sigma_s^y \sin((z/d) - (\pi/4)) \};$$

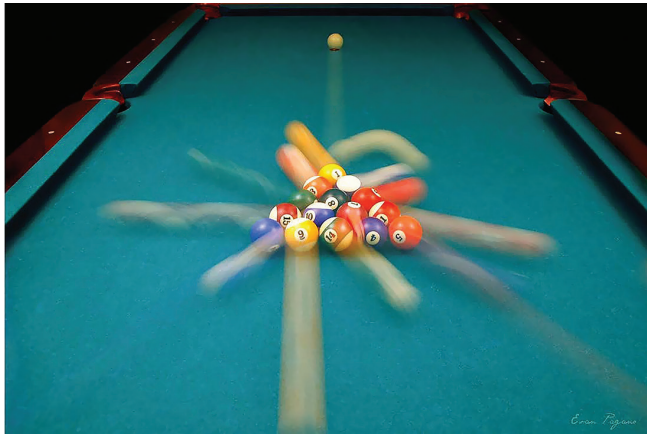
$$v_y = v_{y0} + \sqrt{2} (fd)^{-1} \{ \sigma_s^y \cos((z/d) - (\pi/4)) + \sigma_s^x \sin((z/d) - (\pi/4)) \};$$

$$v_z = (f\rho_0)^{-1} \{ [(\partial \sigma_s^x / \partial x) + (\partial \sigma_s^y / \partial y)] e^{z/d} \sin(z/d) + [(\partial \sigma_s^y / \partial x) - (\partial \sigma_s^x / \partial y)] [1 - e^{z/d} \cos(z/d)] \},$$

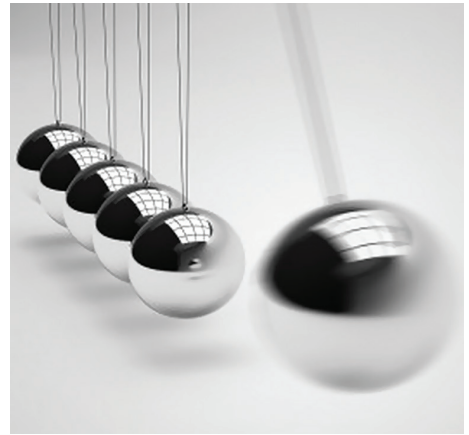
where $d = \sqrt{(2(K_m/f_{Cor}))}$ is a dimensional factor, and $v_{x,0}$ is background velocity (at a DISTANCE far enough from the iceberg to ignore local influences). The curl velocity in the z -direction (v_z) is referred to as the “Ekman spiral.” Taking the integral over the displaced volume the movement is shown to be clockwise from the flow. However, this holds true only for the Northern hemisphere (Ekman’s point of reference), a sign conversion is required for the southern hemisphere. The total momentum with respect to the object at DRIFT per unit surface is $p = -(iK_m/2\varpi\rho_0)$, where ϖ follows from $2\varpi v_x = \eta^* (\partial^2 v_y / \partial z^2)$ and η^* represents the coefficient of viscosity per mass density and can be derived from the one-dimensional equation of MOTION for incompressible flow (ignoring the pressure gradient; derived by CLAUDE-LOUIS NAVIER [1785–1836] and SIMÉON DENIS POISSON [1781–1840]): $\partial v_x / \partial t = \eta^* (\partial^2 v_x / \partial z^2)$; note that $\partial v_x / \partial z$ is the vorticity for the flow.

Elastic collision

[general, nuclear] Collision where no kinetic energy is lost. Both conservation of momentum and conservation of *kinetic* energy apply. In general, MACROSCOPIC collisions are not ideal elastic due to deformations energy, residual FRICTION (rolling or translational), as well as AIR resistance. Objects sliding under the influence of MAGNETIC LEVITATION will still experience some form of deformation that is gradually depleting the system of energy. The same applies to objects floating on an air cushion. Collisions of SUBATOMIC PARTICLES under the influence of ELECTROSTATIC FORCE (Coulomb law) will be most representative of elastic collisions (see Figure E.23).



(a)



(b)

Figure E.23 (a) Example of idealized elastic collisions in the game of billiards, or pool (Courtesy of Evan Pagano.) and (b) knocking ball on a pendulum string suspension.

Elastic energy (PE_e)

[general, mechanics] Energy stored in a compressible medium, which can be a spring or a GAS, which is released when the spring/gas expands. For a spring, the potential energy is proportional to the material constant of the spring, the spring constant (k_s), and the displacement (s) squared as $PE_e = (1/2)k_s s^2$, whereas for a compressed gas this becomes, assuming ADIABATIC COMPRESSION and EXPANSION for an IDEAL GAS with SPECIFIC HEAT c_p (for instance, a compressor), where the temperature changes during compression from T_1 to T_2 , as the pressure changes from P_1 to P_2 , with a corresponding change in volume V . The compression the potential energy equals the amount of work performed, based on the change in ENTHALPY (H) and the TEMPERATURE (T) multiplied by the change in entropy (S), for a reversible process $PE_e = T\Delta S + \Delta H$; this provides $PE_e = c_p T_1 \left[\left(P_2 / P_1 \right)^{(\gamma-1)/\gamma} - 1 \right] = (1/(\gamma-1)) P_1 V_1 \left[\left(P_2 / P_1 \right)^{(\gamma-1)/\gamma} - 1 \right]$ for an ISENTROPIC PROCESS, where $\gamma = (c_p / c_v)$ is the ratio of the specific heats. For an ideal isothermal compression, the potential energy stored by compression equals the work from the integral: $PE_e = \int_{V_1}^{V_2} P dV = K_T \left\{ \left[V_2^{1-\gamma} - V_1^{1-\gamma} \right] / (1-\gamma) \right\} - P_0 (V_2 - V_1)$, where for an ADIABATIC PROCESS $PV^\gamma = K_T$, with $K_T = -(1/V)(\partial V / \partial P)_T$ representing the coefficient of isothermal compressibility. Note that during combustion the change in enthalpy during the chemical reaction needs to be included to obtain the total “elastic” energy, and needs to be integrated over time to yield the change in mass for the rate of change in mass for the chemical reaction (see Figure E.24).



Figure E.24 Elastic energy in a bungee jump.

Elastic force (spring) constant (k)

[general] See SPRING CONSTANT.

Elastic limit

[general] The stretch allowed before deformation or failure sets in (see [Figure E.25](#)).



Figure E.25 The second image from the left may result in elastic return to the original configuration upon release of the applied tension.

Elastic modulus (E_*)

[general, mechanics] See **YOUNG'S MODULUS** (Y_n).

Elastic restoring force

[general] See **SPRING**.

Elastic scattering

[nuclear] See **COMPTON SCATTERING** (*also see* **CROSS SECTION** *and* **NUCLEAR REACTION**).

Elastic shear strain

[general] See **SHEAR STRAIN**.

Elastic stiffness constant

[acoustics, mechanics] See **ELASTIC MODULUS** (*also see* **ELASTIC CONSTANT**).

Elastic wave

[acoustics, imaging, mechanics] Longitudinal compression **WAVE** in solids or fluids as well as the transverse wave on a string or rope. Elastic waves are the fundamental phenomenon for transmission of **SOUND** waves. Temporal and spatial fluctuations in local stress (as a function of location $\vec{r}$) and strain form a system of second rank tensors, called “dyadic.” Stress waves can be internal waves in isotropic or inhomogeneous media, as well as irrotational waves (longitudinal) and solenoidal (transverse), next to **SURFACE WAVES**. **ULTRASONIC IMAGING** relies on bulk waves in isotropic media (primarily in first-order approximation). These waves are described by the **WAVE EQUATION** for a medium of unperturbed density ρ_0 , implementing **HOOKE'S LAW**: $(\lambda_\ell + \mu_\ell) \nabla \nabla \cdot \vec{r} + \mu \nabla \cdot \nabla \vec{r} = \rho_0 (\partial^2 \vec{r} / \partial t^2)$, with the Lamé coefficients $\mu_\ell = (\sigma_s / \mu_s)$, which is equal to the shear modulus, μ_s the shear strain and σ_s the shear stress, and $\lambda_\ell = B_\ell - (2/3)\mu_\ell$ the Lamé strain coefficient, with $B_\ell = P / \mu_s$ being the bulk modulus, μ_s the shear strain, and P the pressure. For irrotational waves, the wave equation becomes $\nabla \cdot \nabla \vec{r} = (1/c_\ell^2) (\partial^2 \vec{r} / \partial t^2)$, where $c_\ell^2 = (\lambda_\ell + 2\mu_\ell) / \rho_0$ represents the displacement wave velocity. For solenoidal waves, the equation changes with respect to the expression for the speed of sound as $c_s^2 = \mu_\ell / \rho_0 = Y_n / 2(1 + \sigma) \rho_0$, where Y_n is Young's modulus, and σ = the shear stress;

under solenoidal FLOW $\nabla \cdot \vec{r}$ vanishes and hence the wave-equation becomes: $\nabla \cdot \nabla \vec{r} = (1/c_s^2) (\partial^2 \vec{r} / \partial t^2)$. For surface waves, see WATER WAVE and WAVE (see Figure E.26).

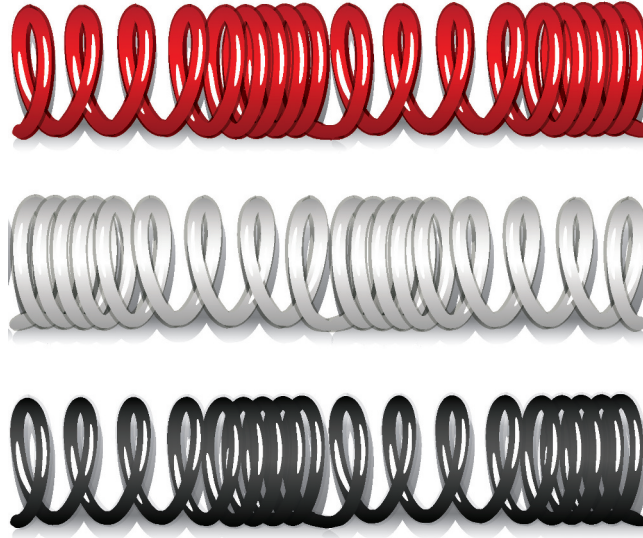


Figure E.26 Longitudinal elastic compression wave.

Elasticity

[atomic, general, nuclear] The phenomenon of elasticity was studied with great detail by GALILEO GALILEI (1564–1642), but the interest predates this era by centuries. The majority of the knowledge of elasticity is derived from the experimental and theoretical description of LATTICE vibrations. Specifically, the propagation of long WAVELENGTH ($\lambda \gg a$, where a is the characteristic dimension of the atomic lattice structure, also LATTICE SPACING) waves in materials has a well-defined pattern that complies with HOOKE'S LAW for the MACROSCOPIC stress and strain. In classical lattice vibrations, the ions are represented as cores with shells of electrons. The electron shell is attached to the nondeformable core by springs. Note that for the inelastic case, the model will include a dampener (e.g., DASHPOT). The springs primarily represent the COULOMB FORCES (ionic and polarized) reducing the model to a MASS-ON-A-SPRING with associated HARMONIC OSCILLATION configurations. Because most materials are anisotropic, HOOKE'S LAW forms a vector description for the stress (σ) to strain (ϵ) relationship:

$$\sigma_m = C_{mn} \begin{bmatrix} \epsilon_1 & \cdots & \vdots \\ \vdots & \ddots & \vdots \\ \cdots & \epsilon_m \end{bmatrix} = \begin{bmatrix} C_{11}\epsilon_1 & \cdots & C_{1m}\epsilon_m \\ \vdots & \ddots & \vdots \\ C_{n1}\epsilon_1 & \cdots & C_{nm}\epsilon_m \end{bmatrix}$$

or expressed as a TENSOR: $\sigma_{ik} = c_{ijkl}\epsilon_{jl}$, with σ_{ik} the dimensional components of the full-deformational stress, ϵ_{jl} the dimensional components of the full-deformational strain and c_{ijkl} the ELASTIC STIFFNESS CONSTANT for each degree of freedom (generally six DEGREES OF FREEDOM total, $m = n = 6$), and the subscript indicates the degrees of freedom, also the notation indicating the position in the MATRIX ELEMENTS. In CARTESIAN COORDINATES the displacement in the x , y , and z direction is u, v , and w , respectively. The stain tensor components are directly related to the displacement as $\epsilon_1 = \partial u / \partial x$, $\epsilon_2 = \partial v / \partial y$, $\epsilon_3 = \partial w / \partial z$, $\epsilon_4 = ((\partial v / \partial z) + (\partial w / \partial y))$, $\epsilon_5 = ((\partial u / \partial z) + (\partial w / \partial x))$, and $\epsilon_6 = ((\partial u / \partial y) + (\partial v / \partial x))$. Written out for the first and the last vector ELEMENT multiplication this shows as follows: $\sigma_1^P = C_{11}\epsilon_1 + C_{12}\epsilon_2 + C_{13}\epsilon_3 + C_{14}\epsilon_4 + C_{15}\epsilon_5 + C_{16}\epsilon_6$, where the superscript P refers to pressure or stress,

which accounts for the first three equations. Equivalent $\sigma_6^S = C_{61}\epsilon_1 + C_{62}\epsilon_2 + C_{63}\epsilon_3 + C_{64}\epsilon_4 + C_{65}\epsilon_5 + C_{66}\epsilon_6$, where the superscript S refers to shear stress, which accounts for the lower three equations. In the case of a crystal with a cubic lattice, the matrix is symmetric $C_{11} = C_{22} = C_{33}$, $C_{44} = C_{55} = C_{66}$, $C_{12} = C_{23} = C_{31}$, and $C_{14} = C_{15} = C_{16} = C_{34} = C_{35} = C_{36} = C_{24} = C_{25} = C_{26} = C_{45} = C_{46} = C_{56} = 0$. In the matrix notation, the shear modulus of a cubic crystal is the coefficient of the element on the diagonal below center $S_{\text{cub}} = C_{44}$, also **MODULUS OF RIGIDITY**. In the case of a centralized force between the ions of the cubic lattice the relationship between the elastic stiffness coefficients is defined by the Cauchy relation as $C_{12} = C_{44} = S_{\text{cub}}$. WAVE propagation in elastic solids can be described with the help of these matrix terms for instance in the x -direction with displacement u as follows: $\rho(\partial^2 u / \partial t^2) = (\partial \sigma_1 / \partial x) + (\partial \sigma_6 / \partial y) + (\partial \sigma_5 / \partial z) = C_{11}(\partial \epsilon_1 / \partial x) + C_{12}((\partial \epsilon_2 / \partial x) + (\partial \epsilon_3 / \partial x)) + C_{44}((\partial \epsilon_6 / \partial y) + (\partial \epsilon_5 / \partial z))$ in Cartesian coordinates with ρ the local density. The last part of the equation is specifically for a cubic crystal.

Elasticity number ($El = \theta_r \eta / \rho R^2$)

[mechanics] Pertaining to **VISCOELASTIC FLOW**, the dimensionless number that relates the ratio of the elastic force to the inertial force. The viscous force is defined by the coefficient of **VISCOSITY**: η , with an additional term representing the **RELAXATION TIME** of the event: θ_r , with ρ the density of the **FLUID IN MOTION** and R the radius of the **PIPE** in which the flow occurs or half the width of the canal. The viscous force provides a mechanism of dampening the inertial forces. Elasticity number provides a range of boundary conditions which yield conditions that result in **EXPANSION** or **contraction** associated with the fluid **VISCOELASTICITY**. This number is applicable to both **NEWTONIAN** and **NON-NEWTONIAN** media.

Elasticity of gases

[hydrodynamics] Gases have an inherent elastic property due to compression mechanism (see **ELASTIC ENERGY** and **IDEAL GAS**).

Elasticity of wall of pipe

[fluid dynamics] The **EXPANSION** of a flexible tube with diameter D and **WALL** thickness t given as: $B_{\text{eq}} = tE/D$, where $t \ll D$, and the elastic modulus of the wall material E (also see **WATER HAMMER** and **COMPLIANCE**) (see [Figure E.27](#)).

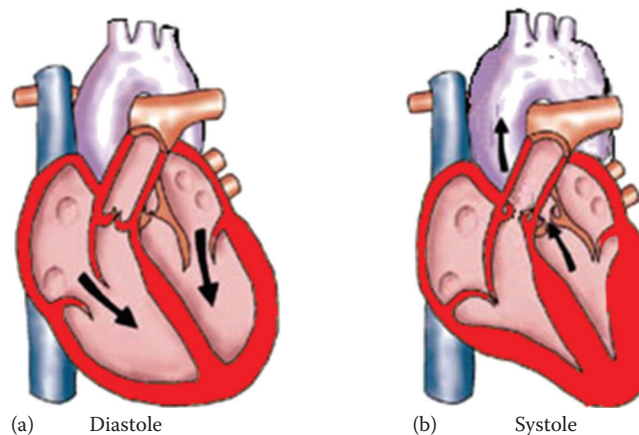


Figure E.27 (a) Elastic expansion of the aorta during systolic filling with large quantity of blood while (b) the flow is restricted by peripheral resistance in the arterioles and capillaries.

Elastin

[biomedical, general] Connective biological tissue that has significant stretch properties, such as those found in the SKIN and in the arterial blood-vessels as well as in the veins, where the VEIN has additional SMOOTH MUSCLE tissue. The ELASTIN provides a COMPLIANCE that is equivalent to the Windkessel effect (see Figure E.28).

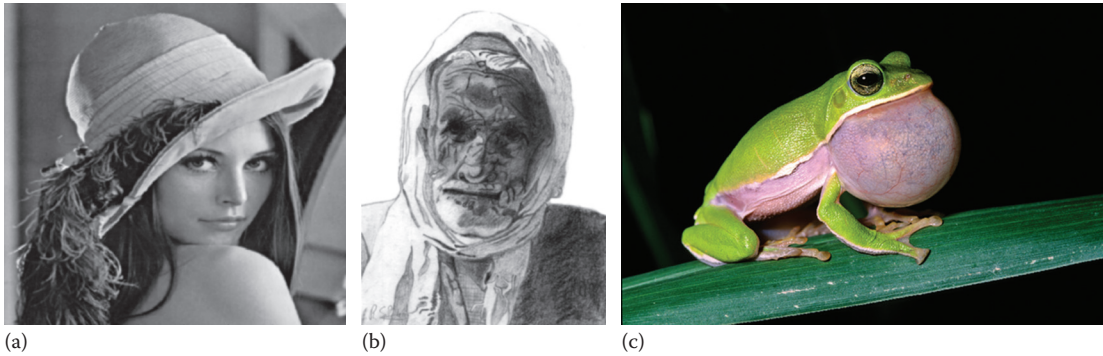


Figure E.28 Elastin of the skin reduces with age: (a) healthy complexion of young elastic skin, (b) old skin with fixed wrinkles and loss of elasticity, and (c) elastic skin of a Taiwanese tree frog.

Elastomer

[chemical, fluid dynamics, mechanics] Elastic POLYMER with high yield-strain value (i.e., resilient) and generally in solid form has a low elastic modulus (Young's modulus). Elastomers have mechanical properties that are similar to rubber, and are formed by either vulcanization (thermal setting; thermoset) providing thermal cross-linking (forming irreversible chemical bonds) or by means of thermal blending, where the material is moldable—semi-LIQUID state—above a certain temperature (the “glass temperature”) while it sets to a solid state when the material cools down (thermoplastic elastomer; reversible; which makes them ideal for mold forming). Thermoplastic elastomers are frequently used in injection molding (see Figure E.29).



Figure E.29 Typical elastomer: surgical gloves.

Electric battery

[general] *See* BATTERY.

Electric car

[general] An automobile that has a primary ENGINE that consists of an electric MOTOR. Frequently, the electric motor is mounted directly on the axis of the car, making the axis a direct and integral part of the armature of the induction process. The ELECTRIC CAR requires the use of a significant BATTERY bank to provide an acceptable travel DISTANCE with having to stop for adding energy (see [Figure E.30](#)).



Figure E.30 The electric car concept: automobiles charging at a public electrical distribution center.

Electric charge

[atomic, electronics, general, nuclear] It is a net charge, primarily because of an excess or deficit in electrons; on a nuclear scale, because of positrons and protons and their respective antiparticles. The earliest documented description of electric charge dates back to 600 BC and the work of the scientist from Greece THALES OF MILETUS (c. 624–546 BC; known as Thales [Θαλῆς]), describing rubbing AMBER and cat fur to generate a form of attraction and repulsion with other objects (*see* ELECTRON CHARGE).

Electric current (*I*)

[atomic, electronics, general] Transport of electrons that are released from the atomic and molecular VALENCE BAND to become free electrons under an applied external electric field resulting from a potential difference across the CONDUCTOR. The current was initially assumed to be the result of POSITIVE CHARGE migration, however, later to be refuted as NEGATIVE CHARGE carriers; hence the electrons move in the opposite direction of the direction of the current, introducing the concept of “hole” migration providing the current in the appropriate direction. Electric current was recognized by Count ALESSANDRO GIUSEPPE ANTONIO ANASTASIO VOLTA (1745–1827) in 1800, fueled by the research conducted by his colleague LUIGI GALVANI (1737–1789) in 1780; however, the electron itself was discovered in 1897 by JOSEPH JOHN THOMSON (1856–1940). The holes represent the missing electrons in the atomic structure. A current is the end result of the movement of all electrons in a conductor, which means that the first electron out is the closest to the terminal; the electron does not have to travel from pole to pole on the potential source. The conduction process may be compared to a tube filled with marbles, where injecting one marble on one side will eject a marble on the opposite side almost instantaneously, thus no requirements for QUANTUM mechanical approach in case the electron had to approach the speed of light, hence merely ELECTRON DRIFT VELOCITY.

Electric dipole

[biomedical, chemical, condensed matter, electronics, solid-state] Charge distribution that is weighted with excess POSITIVE CHARGE on one side and excess NEGATIVE CHARGE on the opposite side. Dipoles can be molecular (e.g., H_2O), ions (missing electrons or captured electrons) and can also be on a MACROSCOPIC scale where the charge distribution in an object (isolator or semiconductor) has permanently been shifted to form a permanent DIPOLE or the influence of an external electric field temporarily moves the electrons in a CONDUCTOR to one side, hence creating a deficit (holes) on the opposite side. In a semiconductor or INSULATOR electrons may be added to the medium by means of charge transfer from another object. Animals may also create a whole-body dipole which they use for sensing purposes. The platypus and the Elephant fish (*Gnathonemus*) are only two examples of many animals that form a static electric field due to an induced dipole. These animals also have the ability to sense spatial changes to the electric field distribution, hence allowing for navigation as well as for seeking prey. The dipole attraction is very strong and forms one of several chemical binding mechanisms (see Figure E.31).

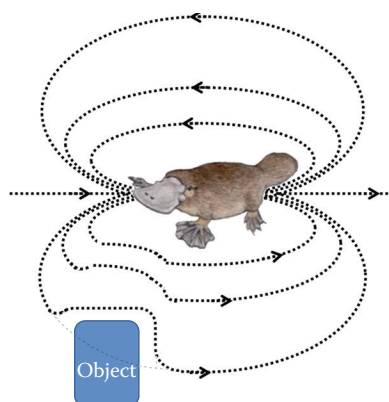


Figure E.31 Electric dipole: specifically used for navigation by certain animals.

Electric dipole moment

[atomic, condensed matter, nuclear] The moment expressed by a set of equal but opposite charges ($+q$ and $-q$) at a fixed separation DISTANCE (d) in direction $\vec{t}$, pointing from the positive to the NEGATIVE CHARGE in the respective frame of reference, expressed as $\vec{p} = q\vec{t}$.

Electric dipole transition

[atomic] Electronic transitions in the electronic energy levels or the nuclide structure that results in a nanoscopic shift in charge balance that is governed by the various selection rules for transitions.

Electric field (E)

[atomic, electronics, general, nuclear] The virtual lines connecting migrating out from positive, or alternatively converging on a NEGATIVE CHARGE distribution (Q), with a MAGNITUDE defined by the force per unit charge experienced at any point at a DISTANCE (r) from a charge distribution. The electric field can exist as the result of a single charge with no defined termination; keep in mind that the MAGNETIC FIELD by definition is a closed loop. The electric field is defined by Coulomb's law: $E = (1/4\pi\epsilon_r\epsilon_0)(Q/r^2)$, designed by CHARLES-AUGUSTIN DE COULOMB (1736–1806) in 1785, where ϵ_r represents the RELATIVE PERMITTIVITY and $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ is the permittivity of free space. The work of Coulomb was followed by the work of MICHAEL FARADAY (1791–1867) on ELECTRIC FORCE.

Electric field in conductor

[atomic, electromagnetism, nuclear] It is a function of radius of curvature of the surface contour. Free ELECTRONS are drawn into the electric field in the CONDUCTOR, with a field distribution that depends on the radius of curvature (r), smaller radius higher field due to the higher SURFACE CHARGE-DENSITY ($\rho_e(r)$) as illustrated by $\vec{E}(\vec{r}) = (1/4\pi\epsilon_0) \sum_j (\rho_e(\vec{r}_j)(\vec{r} - \vec{r}_j) dV_j / |\vec{r} - \vec{r}_j|^3)$, where V_j is the localized electrical potential in location $\vec{r}_j$ and ϵ_0 is the DIELECTRIC permittivity. Note that in a conductor the free electrons repel and they all want to be on the surface of the conductor making the description a surface charge density.

Electric field intensity

[atomic, electronics, general, nuclear] MAGNITUDE of the intensity of an electric field at a particular point, equal to the force that would be exerted upon a unit POSITIVE CHARGE placed in the field at that point. The direction of the electric field is the direction of this force.

Electric force

[electromagnetism, general] The fact that opposite (unlike) ELECTRICAL CHARGES (positive vs. NEGATIVE CHARGE) will attract or similar charges repel each other with a force proportional to the inverse of the square of the separation DISTANCE between the net charges. This phenomenon was described in 1760 by DANIEL BERNOULLI (1700–1782) and BENJAMIN FRANKLIN (1706/1705?–1790) in circa 1750. The formal equation was postulated by CHARLES-AUGUSTIN DE COULOMB (1736–1806) in 1785: $F_e = (1/4\pi\epsilon_r\epsilon_0)(Q_1Q_2/r^2)$, where Q_1 and Q_2 are the net charges between which the electric field and resulting electric force is formed, $\epsilon_0 = 8.8541878 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the DIELECTRIC permittivity of VACUUM, ϵ_r the RELATIVE PERMITTIVITY (sometimes also called the “dielectric constant,” which is $\epsilon_r = 1$ for vacuum) and r the separation between the two net charges. The net charge in one location is the sum of all the charges gathered in that one volume in space considered as a unique location.

Electric force, Coulomb’s law

[general] See COULOMB’S LAW.

Electric potential (V)

[computational, electromagnetism, general] The amount of work needed to transport a positive ELECTRIC CHARGE of 1 C from infinity to the point of electric interest. When a cumulative charge is located at this point then work is performed, otherwise no work is performed and no electric potential exists in this point. In case an artificial potential difference is maintained between two points, a GALVANIC MECHANISM needs to maintain a current from the higher electric potential to the lower electric potential, note current is the FLOW of charge. An electric potential can, for instance, be generated by means of the PHOTOELECTRIC EFFECT, using ELECTROMAGNETIC RADIATION to release electrons from their atomic/molecular orbit and hence providing the mechanism of action (the work) to create a potential difference. Other means involve making surface contact between two or more metals (bimetal). The metal-plate electric potential series is a function of both the nature of the metals and the localized temperature. The electric potential exists under the condition of no current (*also see* BATTERY and THERMOCOUPLE). Animals such as the electric eel and electric manta-ray create a high electrical potential by chemical means, reaching several hundred volt. A similar electrochemical process is used in NERVES and MUSCLE cells (*see* NERNST POTENTIAL) for SIGNAL propagation by electrical potentials and muscle contraction.

Electric quadrupole moment (Q_{elect})

[atomic] The NUCLEUS generally does not possess a static DIPOLE moment, but does possess a dynamically fluctuating QUADRUPOLE MOMENT. The measure of eccentricity of the ellipsoidal surface of the nucleus is defined as $Q_{\text{elect}} = (1/e) \int (3z^2 - r^2) \rho d\tau$, where $e = 1.60217657 \times 10^{-19} \text{ C}$ is the ELECTRIC CHARGE, z is the location on the major axis of the ellipsoid, r is the DISTANCE from the geometric center, ρ is the charge density of the respective nucleus, and τ is the spatial variable. As an example, the electric quadrupole moment for the ^2_1H hydrogen nucleus is $Q_{\text{elect}} = +0.00282 \times 10^{-24} \text{ cm}^2$, and for $^{235}_{92}\text{U}$ uranium: $Q_{\text{elect}} = \pm 4.1 \times 10^{-24} \text{ cm}^2$.

Electricity

[atomic, general, nuclear] Property of ELECTRIC CHARGE concentrations, either stationary or in MOTION, primarily pertaining to the mobility of free electrons, which can be released from VALENCE electrons bands in conductors and SEMICONDUCTORS. The phenomenon of electricity was studied with great detail by GALILEO GALILEI (1564–1642), but the interest predates this era by centuries. The earliest recorded description with respect to static electricity dates back to THALES OF MILETUS (c. 624–546 BC) a scientist from Greece, known as Thales [Θαλῆς]. Thales described rubbing AMBER and cat fur to generate a form of attraction and repulsion with other objects. Modern concepts of electricity include the generation of electric power by generators and the current FLOW between a potential difference as defined through the COULOMB POTENTIAL (see Figure E.32).

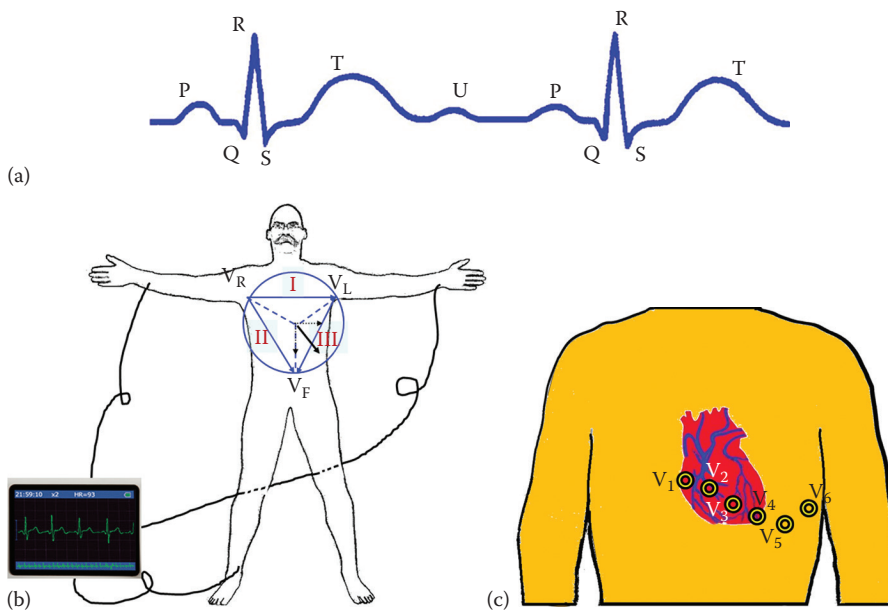


Figure E.32 (a) ElectroCardioGram (ECG; sometimes also referred to as EKG [electrokardiogram]) with the P-wave from the depolarization of the atrium, followed by the ventricular depolarization QRS-complex. (b) Generally, the ECG is collected from electrodes placed on the skin; either, the wrists and ankles (Einthoven electrode placement), or (c) more detailed information obtained with electrodes placed on the chest (Goldman electrode placement).

(Continued)

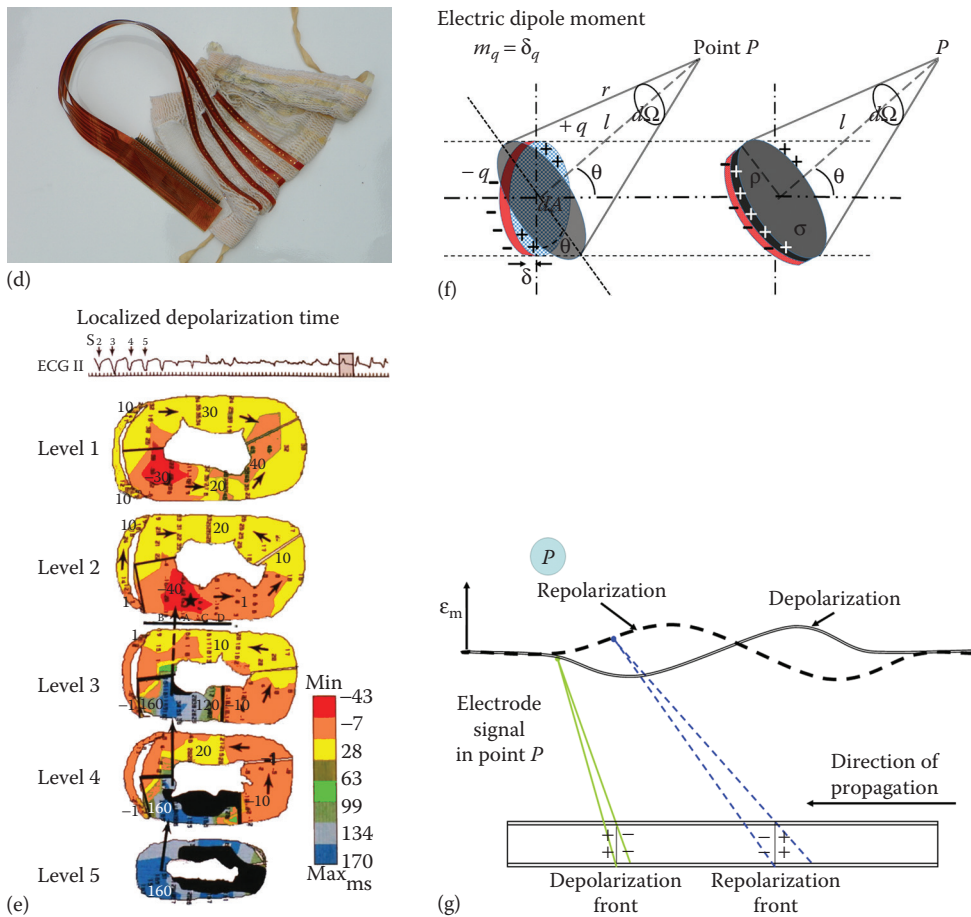


Figure E.32 (Continued) Further detail can be achieved during open-chest surgery with (d) an, electrode sock placed around the heart or by needles inserted into the heart. The needles and the sock circumvent the volume conduction aspect and the associated time and location averaging of the cellular depolarization superposition when measuring a great distance based on the current produced as a result of the time-dependent electrical potential difference of the action potential of the heart muscle cells. (e) The location and time specific electrical depolarization is presented for the electrode configuration outlined in (c), (f) the registration of the single cell electrical depolarization is affected by volume conduction where the electrode is placed in point P , (g) the collected signal is the result of an electrical dipole of the depolarizing cell outlined in with the "front" depolarization and "back-side" repolarization providing a biphasic and triphasic potential.

Electrocardiogram (ECG)

[biomedical, electromagnetism] When MUSCLE cells depolarize during contraction, specifically for the cardiac muscle (i.e., HEART), the cell's intrinsic DIPOLE LAYER reverses polarity, creating a change in the electrical potential at a DISTANCE from the electric bilayer. It is also found as ElectroKardioGram (EKG) on historical basis, as designed by WILLEM EINTHOVEN (1860–1927), the scientist and physiologist from the Netherlands. This process is periodic and repeats every heartbeat, which is approximately once every second, but in reality ranging from approximately 1 BEATS per minute to over 200 beats per minute, depending on the size of the hemodynamic system of the animal. Larger animals will by definition have a slower heart rate; babies have a heart rate over 100 beats per minute, whereas the average healthy adult has at approximately 75 beats per minute at rest. Electrodes placed on the surface of the chest of the animal in location P measure the propagation of the DEPOLARIZATION dipole layer at an arbitrary distance away from the ACTION POTENTIAL. By the time the electrical potential as a function of time reaches the respective electrodes, the conduction volume between the source and the detection will have dispersed and attenuated the vectorial profile of the electrical

potential as a function of the conductive, semiconductive, and insulating (e.g., AIR in lungs) components in the path of the depolarization WAVE that traverses the inhomogeneous tissues with the mathematical description defined by the TELEGRAPH EQUATION. Electrodes can be placed in various numbers and in a variety of placement configurations, ranging from 3 (wrists and one ankle, or patches on the chest) to 12 in a well-designed pattern on chest and back that allows for reproducible and interpersonal analysis and comparison. The larger the number of electrodes, the higher the accuracy in recreating the vector displacement of the electrical potential. The volume conduction of the electrical impulses will influence the delays in action potential as a function of location, as will it affect the way the depolarization WAVEFRONT is viewed: depolarizing in positive or negative direction based on the dipole moment of the axon, or cluster of cells and the respective configuration in view of the distant ELECTRODE. In the computational approach, several assumptions need to be made, the first being that the medium surrounding the location as a function of time for the action potential is infinitely spread out in all directions. The second assumption implicates that the CELL that produces the action potential has ideal cylinder symmetry (both for a single muscle cell as well as for an axon of a nerve), and that the MEMBRANE thickness is negligible in comparison to the cell dimensions. The membrane is a dipole layer with surface charge density σ_{charge} , and dipole moment per unit surface area: $m_{\text{dipole}} = (q\delta/A) = \sigma_{\text{charge}}\delta$, now δ the "plate separation." The cell at rest has a potential of -90 mV. The potential in the external point P is influenced by two oppositely charged dipole layers, with equal contributions. The SOLID ANGLE of influence and the dipole moments per surface area are identical. Hence, the front and back sides of the cell cancel each other out, and no potential is registered in P for a cell in steady-state potential and cannot be detected. During the depolarization process, the chemical ION transfer is not considered to be influencing the development of the action potential geometrically, no gradients in Na^+ and subsequent K^+ ions. The resulting depolarization propagation now has two discontinuities, the depolarization front and the repolarization front. Both move transporting along the length of the cell cylinder. In the propagation process, the depolarization will be limited to a short cell segment only, with the distal portion of the nerve cell still in EQUILIBRIUM STATE and the trailing end going through the process of repolarization and subsequent equilibrium. The depolarized section of the cell is defined by the dipole moment per unit area $m_{\text{dipole},2}$, and the equilibrium section of the cell has dipole moment per unit area $m_{\text{dipole},1}$. Only within the narrow solid angle that encloses the transition ring on the tube geometry that is converting from equilibrium to depolarized state will provide an electrical dipole and associated potential that can be detected: $dV_p = K(m_{\text{dipole}} \cdot dA/r^3) = K(m_{\text{dipole}} \cos \theta dA/r^2) = Km_{\text{dipole}} d\Omega$, where Ω is the solid angle, K is a constant, and r is the distance between the dipole and point P , subsequently integrated over the full solid angle for total effect. The electrical potential in point P as a result of the depolarization is formed by the combined effect of all electrical activation within a solid angle of view of the detector: both "front" and "back" side of the cell under depolarization, as well as the sides. The total electrical influence on the electrode in position P is the combined effect of the proximal (Ω_p) and distal (Ω_d) contributions, formulated as $V_p = K(m_{\text{dipole},1} + m_{\text{dipole},2})\Omega_p - K(m_{\text{dipole},1} + m_{\text{dipole},2})\Omega_d$. The cross-sectional projection can be represented as two cross-sectional charge disks in the cylindrical cell within the same solid angle, simplifying the mathematical description of a propagating depolarization wave front. The distal segment, captured within Ω_d , will generate a negative potential because a net NEGATIVE CHARGE is on the side of the electrode. During the transport of the depolarization wave front, the distance separating the depolarization front and the repolarization front can be determined from the duration (t) of the action potential combined with the speed of propagation (v_{signal}) of the SIGNAL along the CELL MEMBRANE ($x = vt$). For instance, if the depolarization process takes place over a time frame of 1 ms ($t = 1$ ms), and the propagation velocity is $v_{\text{signal}} = 2$ m/s, the distance becomes $h = 2$ mm. Because of the propagation of the depolarization front along the WALL of the cell, the angle with respect to the electrode in point P of the dipoles will continuously change in time. In the discussion, there is no difference whether the depolarization front moves with respect to the in situ electrode, or if the electrode moves and the depolarization remains stationary, although in practice the latter is not practical. The depolarization wave front and the associated dipole migration can be described by a MOTION algorithm. The repolarization follows an identical process. Using the angle with respect to the normal to the cell wall as a reference, the solid angle capturing the event will initially increase and subsequently decrease and will be nonexistent when the depolarization is directly underneath the normal pointing at P . Based on this mathematical feature as well as the distance aspect, the electrical dipole potential initially increases in approach

to the electrode, and subsequently decreases to zero. After passing the normal position with respect to position *P*, the electrical potential renders a negative value. This type of fluctuation in electrical potential is referred to a “biphasic action potential.” The superposition of both the depolarization and repolarization wave front generates a triphasic action potential (see [Figure E.33](#)).

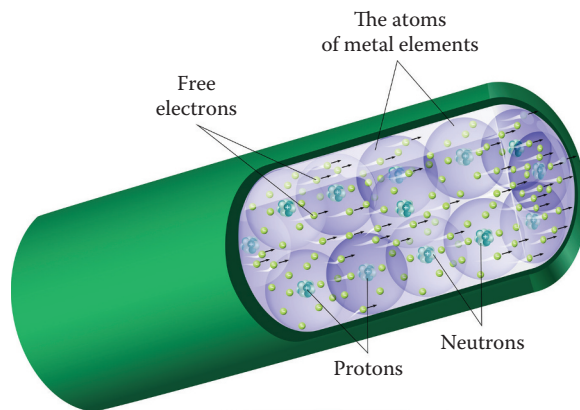


Figure E.33 Schematic of electric current.

Electrochemical equivalent

[atomic, general, nuclear, quantum, thermodynamics] The amount of MATTER involved in ELECTROLYSIS under the FIRST LAW OF FARADAY that transports one (1) coulomb of ELECTRIC CHARGE, or the ionic quantity (e.g., acids, bases, and SALT solutions) that is transported between the CATHODE and ANODE in a LIQUID under exposure to 1 AMPERE for 1 s. For instance, the silver in the electrochemical equivalent is 1.118 mg. Similar conditions apply for molten salts.

Electrode

[biomedical, electronics, general] Conducting pole attached to a wire that leads to a recording device. The electrode is designed to collect electrical ACTIVITY (conduct current to measure an electrical potential) for diagnostic purposes. The electrodes may be used to pinpoint electronic behavior of an electronic circuit, or perform nondestructive testing on CONDUCTOR and semiconductor-based materials with applied current frequency range from 0 Hz to 2 MHz. Additional use of electrodes is in biomedical applications with respect to any cellular DEPOLARIZATION, ranging from MUSCLE to brain activity to the rhythm analysis of the HEART as well as nerve pulse propagation and sensory validation from the organ to the spinal cord to the brain, respectively. Biological defects may be identified this way as well as electronic design flaws and component failure. Generally, electrode are designed for external use as a pin or pad; however, additional applications may require a needle electrode for invasive studies. The external electrodes for biological use can be attached to a sticky tape or a miniature suction cup. Generally, a reference electrode is required to provide a baseline to which the diagnostic MEASUREMENT is checked for validity. Whole EARTH GROUND will, by definition, provide a reference potential of 0 V, whereas on the HUMAN BODY, the reference electrode frequently needs to be placed in an inconspicuous place, where in theory, all time-dependent signals will cancel out, hence only a relative measurement is performed in contrast to absolute measurements in ELECTRONICS.

Electrodynamics

[general] The field of electrical ENGINEERING pertaining to the influence of electric currents on each other and the energetic content of electric phenomena. This electrodynamics is in contrast to ELECTROSTATICS and is a subcategory in PHYSICS or electrical engineering.

Electroencephalogram (EEG)

[biomedical] Electrical potential distribution recording resulting from brain ACTIVITY. Because of the complex three-dimensional structure of the brain and the excitation at multiple locations in a simultaneous or dissimilar fashion, the retracing effort will depend on retracing the volume discharges as a function of location in time recorded over the surface of the skull (see VOLUME CONDUCTION and the description of electrical mapping during an ELECTROCARDIOGRAM) (see Figure E.34).

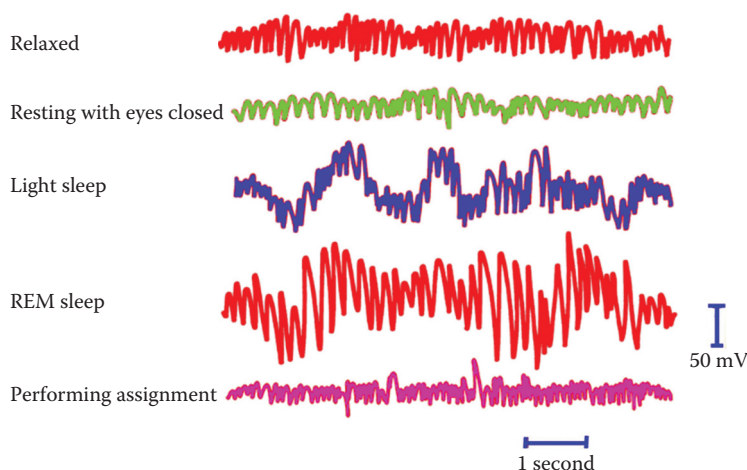


Figure E.34 The collection of brain wave patterns, grouped by frequency pattern.

Electroluminescence

[general] The phenomenon of emission of visible light from an object during or shortly after exposure to electric discharge and associated electric field (high MAGNITUDE), irradiation by CATHODE RAYS, alpha, or beta RADIATION. A special case is the scintillation of materials such as zinc sulfite and diamond under alpha radiation exposure. Electroluminescence is the mechanism resulting from recombination of electrons and depleted atomic or molecular structures in a material, frequently of semiconductor nature. The accelerated electrons that are captured or excited in the process release their energy as photons, which is the standard mechanism of action (see Figure E.35).



Figure E.35 Electroluminescence on the front panel of an electrode beam tube (cathode ray tube: CRT).

Electrolysis

[atomic, electromagnetism, general, quantum, solid-state] The chemical separation of ELEMENTS by means of passing an electrical current through the medium, primarily in SOLUTION. The electric current FLOW between two conductors called the CATHODE and the ANODE in a solution. The class of chemical substances that allow this process

to take place is called an “ELECTROLYTE.” The electrolyte conducts the electric current by means of ionic migration (ION-flow, or a form of displacement current). The FIRST LAW OF FARADAY states that the quantity of released material (i.e., ionic gas or solution) is directly equivalent to the applied current and time duration. This law is supported by the electron valance of the molecules and atoms involved in the process, which also correlates to the transported mass. The transported MATTER during electrolysis is called the ELECTROCHEMICAL EQUIVALENT.

Electrolyte

[biomedical, general, quantum] Mixture of constituents that is separated under passing an electric current through the substance. The substance can be SALT solutions and watery acids or bases as well as molten salts. The electrolytes are the split constituent molecules or atoms containing positive or NEGATIVE CHARGE: ions.

Electrolytic capacitor

[atomic, electromagnetism, general] CAPACITOR that has a capacitive value that is directly proportional to the surface area of the opposing plates and inversely proportional to the DISTANCE between the plates. The metallic plates are suspended in ELECTROLYTE solution. Under initial current, the plates form a molecular oxide layer that acts as INSULATOR, preventing further current passage. The separation distance is usually reduced to the combined thickness of the oxide layers. Electrolytic capacitors are rendered inactive under alternating current due to the breakdown of the oxide layer and hence only operate under direct current.

Electrolytic dissociation

[atomic, electromagnetism, general] The splitting of a mixture in its respective constituents when exposed to a medium, for instance, in SOLUTION. SVANTE AUGUST ARRHENIUS (1859–1927) developed a theoretical description of the chemical process.

Electromagnet

[electronics, general] Device designed to produce a MAGNETIC FIELD distribution of a specific configuration based on the passage of a current through a wire that has a particular geometry and layout. Electromagnets are generally designed from coils with multiple windings where the number of loops provides a mechanism to control the MAGNITUDE of the magnetic field. The first electromagnet was built in 1825 by WILLIAM STURGEON (1783–1850) from Great Britain, and this was later improved by JOSEPH HENRY (1797–1878) and released in 1831 (see [Figure E.36](#)).

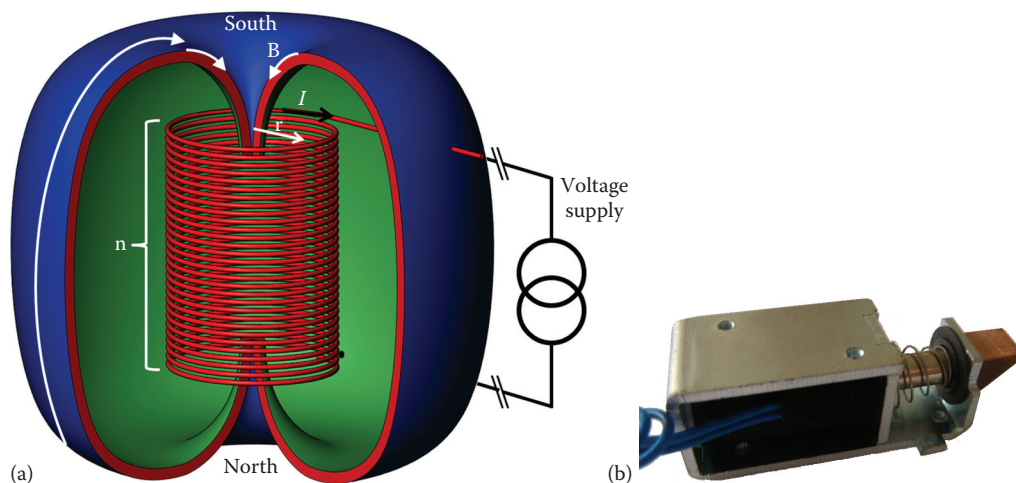


Figure E.36 (a) The design of an electromagnet, generating a magnetic field induced by the current flowing through the coil. The blue surface indicates an isomagnetic field contour. (b) Coil magnet-operated lock.

Electromagnetic charge

[general] The fact that **ELECTRIC CHARGE** has two “distinct electricities” was discovered by the botanist **CHARLES FRANÇOIS DE CISTERNAY DU FAY** (1698–1739) from France in 1734. The earliest documented description of electric charge dates back to 600 BC when **THALES OF MILETUS** (c. 624–546 BC, known as Thales [Θαλῆς]), a scientist and philosopher from Greece, described rubbing **AMBER** and cat fur to generate a form of attraction and repulsion with other objects. However, the physical charge of the electron was not identified until in 1897 by **JOSEPH JOHN THOMSON** (1856–1940) (see **ELECTRIC CHARGE** and **ELECTRIC CURRENT**).

Electromagnetic energy

[atomic, electronics, optics, thermodynamics] The energy contained in the combined electric and magnetic fields associated with the broad spectrum of **ELECTROMAGNETIC RADIATION**. The two components of **ELECTROMAGNETIC RADIATION** are never separated and cannot be considered as independent; however, the electric and the **MAGNETIC FIELD** contributions can be analyzed separately, whereas the combined effect is represented by the Poynting vector. The electric field has an energy density (u_e) that is directly proportional to the **ELECTRIC FIELD** (E) strength squared, in equivalence to the “intensity” for other phenomena such as **ACOUSTIC WAVE ENERGY**: $u_e = (1/2)\epsilon_0 E^2$, where $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ is the permittivity of free space. Similarly, the magnetic field energy density (u_b) is provided by the square of the magnetic field **AMPLITUDE** (B) as $u_b = (1/2)(B^2/\mu_0)$, where $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$ is the permeability of free space (see **POYNTING VECTOR** and **ELECTROMAGNETIC RADIATION**) (see Figure E.37).

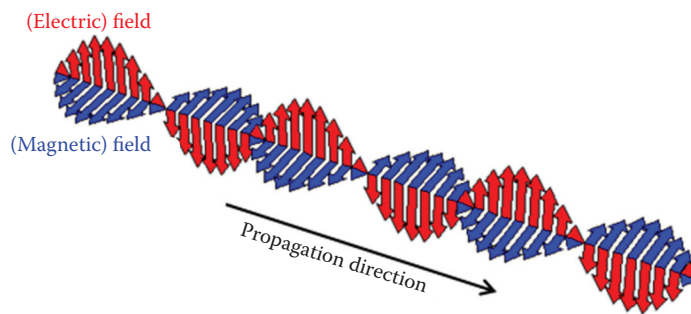


Figure E.37 Graphical representation of the perpendicular positioning of the electric field with respect to the magnetic field in electromagnetic radiation.

Electromagnetic field

[thermodynamics] Interrelated **COHESION** of electric and magnetic fields, based on mutual dependence. The changing electric field indirectly generates a synchronized changing **MAGNETIC FIELD** and vice versa. Only an *accelerated* charge will provide the conditions for a *changing* electric field and hence a changing magnetic field. The theoretical interrelation between the two fields is described by **MAXWELL EQUATIONS** (see **ELECTROMAGNETIC RADIATION**).

Electromagnetic radiation

[atomic, general, nuclear, optics] **RADIATION** composed of an electric field based on Coulomb law and **GAUSS'S LAW** for electric fields, which changes as a function of time due to an accelerating charged **PARTICLE**, which in turn induces a changing **MAGNETIC FIELD**, in principle based on **FARADAY LAW** and **AMPÈRE'S LAW**, where the magnetic field is required to satisfy Gauss' law for magnetic fields. The total electric and magnetic field theory for an accelerated charged particle is captured by slight modifications to the aforementioned laws, next known as “**MAXWELL EQUATIONS**.” On the repercussion side, the charged particle itself will again be subject to electric and magnetic fields during its motions, hence there are constraints to the source outlined by the Lorentz force law.

The currently known electromagnetic radiation spectrum spans a broad wavelength (FREQUENCY SPECTRUM) range from at least as small as 10^{-18} m $\sim 10^{25}$ Hz as gamma radiation to 10^8 m ~ 1 Hz, known as “long-wave radio.” The visible spectrum is approximately from 3.3×10^{-7} m, blue; to 6.6×10^{-7} m, RED. The speed of propagation of electromagnetic radiation was initially determined within 30% of the currently accepted value in 1675 by OLAUS ROEMER (1644–1710). Electromagnetic radiation can be organized in a predictable fashion using a range of theoretical tools developed over the centuries. The laws of Snell with regard to REFLECTION and REFRACTION were introduced around the turn of the sixteenth century by WILLEBRORD SNELL (1580–1626). The HUYGENS’ PRINCIPLE introduced in the seventeenth century by CHRISTIAN HUYGENS (1629–1695) predates the acceptance of the WAVE theory but is phenomenologically correct. The Huygens’ principle introduces the hypothesis that every point in the path of a propagating wave forms a new source, while connecting all the synchronized sources forms a wave front. The blue sky (the background is black because the SUN is only in one location) results from RAYLEIGH SCATTERING as described by JOHN WILLIAM STRUT, THE THIRD BARON RAYLEIGH (1842–1919). Additional more complex RADIATIVE TRANSFER theory describing both galactic propagation and biomedical imaging-related OPTICS was introduced by SUBRAHMANYAN CHANDRASEKHAR (1910–1995). Another interesting theoretical contribution to the PERCEPTION of light was introduced by GUSTAV MIE (1869–1957); although his efforts were initially geared to the quality of printed paper, his work provided significant insight on the interaction of light with large particles, most prominently clouds in the sky. The overcoupling Maxwell theories were introduced by JAMES CLERK MAXWELL (1831–1879) in 1861 (see ELECTROMAGNETIC WAVES). Electromagnetic radiation does not require a medium for propagation, in contrast to ACOUSTIC WAVES. Electromagnetic radiation is emitted from every object with a temperature above ABSOLUTE ZERO due to the thermal agitation on an atomic and molecular level (charge VIBRATION, translation, rotation, and dipole-scissor action). Additional sources of emission are energetic DECAY to a lower energy state by EXCITED STATES of radioactive isotopes, which continues until the final GROUND STATE is eventually reached. CENTIMETER scale waves are generated in a MICROWAVE OVEN, which brings water molecules in RESONANCE, which results in an increase of kinetic energy that is a temperature rise. Long wavelength radiation can be generated by an electronic circuit that sends an oscillating current into an ANTENNA, which is subsequently broadcast as television and RADIO waves. Electromagnetic radiation transposes energy and hence one can attribute momentum. The momentum of electromagnetic radiation may be interpreted partially as SOLAR WIND. The momentum of electromagnetic radiation is the energy divided by the speed of light ($c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-(1/2)} = 2.99792458 \times 10^8$ m/s), or the POYNTING VECTOR ($\vec{S}$) divided by the speed of light squared yields the momentum per unit volume: $\vec{p}' = \vec{S}/c^2$. Keep in mind that the momentum of a single PHOTON is $p_{\text{phot}} = \hbar k = h/\lambda$, for wavelength λ and PLANCK’S CONSTANT: $h = 6.626070040(81) \times 10^{-34}$ m²kg/s(Js). Equivalently, the radiation pressure is the energy squared multiplied by the permittivity of free space, normalized by division by 2, or $P_{\text{rad}} = a(|\vec{S}|/c)$, where $a = 1$ for total absorption and $a = 2$ for total reflection (see Figure E.38).

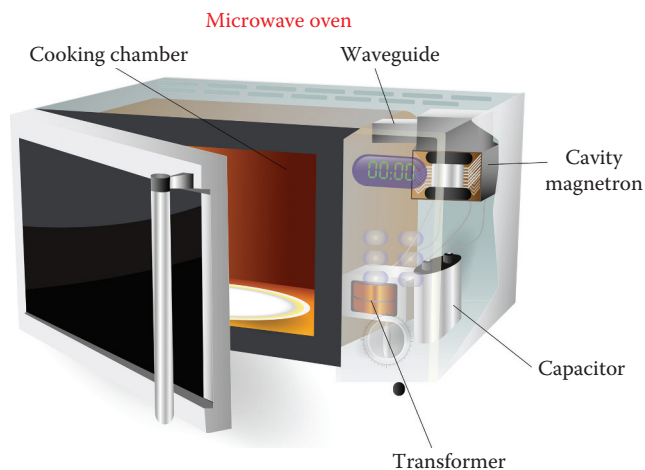


Figure E.38 Microwave “oven” (magnetron), emitting electromagnetic radiation in the GHz range.

Electromagnetic spectrum

[general, nuclear] A synopsis of the EMISSION SPECTRUM of ELECTROMAGNETIC RADIATION is outlined in a graph (see [Figure E.39](#)).

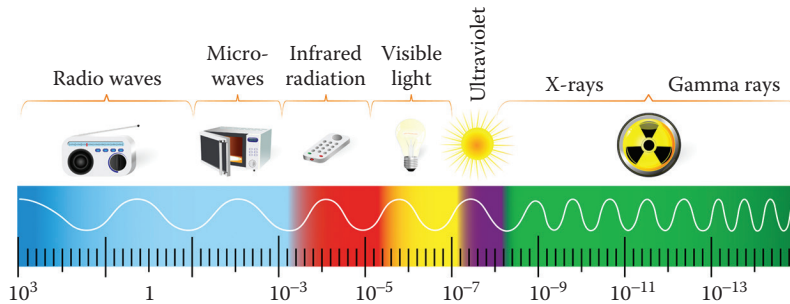


Figure E.39 Representation of the electromagnetic spectrum.

Electromagnetic theory

[atomic, general, imaging, nuclear, optics] See **MAXWELL THEORY**.

Electromagnetic (EM) waves

[computational, electromagnetism, general] Transverse ENERGY WAVES constructed of interrelated periodically changing ELECTRIC FIELD and MAGNETIC FIELD that migrate in synchronized fashion from location to location while remaining in a fixed PHASE relationship. The field lines are always perpendicular to each other in a transverse manner. The interrelation between the electric and magnetic phenomena is defined by the MAXWELL EQUATIONS. No real CURRENT is required to initiate the electric field; a DISPLACEMENT CURRENT resulting from a changing electric field can in turn produce a magnetic field, which inherently changes in a synchronized fashion. EM waves propagate with the SPEED OF LIGHT in the respective MEDIUM. EM waves range from ultra-short GAMMA RAYS to long-wave RADIO WAVES. Visible LIGHT is one specific segment of the total EM SPECTRUM. EM waves are identified by either FREQUENCY (ν) or WAVELENGTH (λ) as all waves (see ELECTROMAGNETIC RADIATION) (see [Figure E.40](#)).

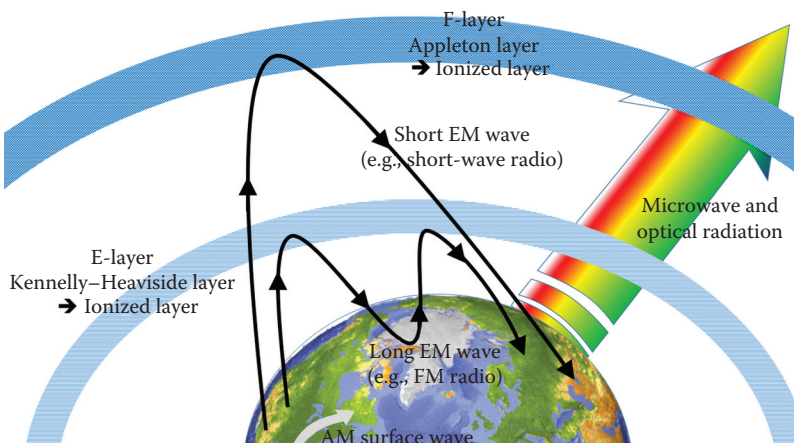


Figure E.40 Color as a function of the electromagnetic wave reflection or absorption.

Electromotive force (ε_{emf})

[general] Based on the Faraday's law of induction a changing magnetic FLUX can generate a voltage known as the "electromotive force." The MAGNETIC FLUX (Φ_M) is a function of both the magnetic field MAGNITUDE (B) and the area (A) that captures the fieldlines: $\varepsilon_{\text{emf}} = -N(\partial\Phi_M/\partial t) = -N((\partial\vec{B} \cdot \vec{A})/\partial t)$, where the wire loop has N windings. Additional contributions to the electromotive force are chemical potential and thermal effects, which yield for the total electromotive force: $\varepsilon_{\text{emf}} = \oint_C (E + \vec{v} \times \vec{B}) d\ell + (1/q)(G/[C])(1/F) + \varepsilon_{\text{emf,Therm}}$. The chemical potential can be found by using the NERNST EQUATION based on the reaction processes, or from the HALF-CELL potential using the Gibbs free energy (G), with the current density J , expressed as $G = q\varepsilon_{\text{emf,Chem}}[C]F$, where $[C]$ is the chemical concentration with charge q in a volume V and F the FARADAY CONSTANT. The thermal electromotive force is more difficult to find and has as foundation the heat of the reaction Q_{chem} , while the temperature is determined by the chemical reaction or influences the chemical reaction as a catalyst, defined as $Q_{\text{chem}} = -q[C]F(\varepsilon_{\text{emf,Therm}} - T(\partial\varepsilon_{\text{emf,Therm}}/\partial T))$. Also see **SEEBECK EFFECT** (named after the German scientist THOMAS JOHANN SEEBECK (1770–1831), who introduced this in 1821) or thermoelectric effect, and see **PELTIER EFFECT**. Other factors may also contribute to the total electrical potential.

Electromyogram

[biomedical, electromagnetism, imaging] MEASUREMENT and display of the electrical DEPOLARIZATION as the initiation process for muscular ACTIVITY, that is, contraction. Depolarization sequence of the MUSCLE measured by electrodes placed on the SKIN or by means of ELECTRODE needles inserted in the muscle. The electromyogram will rely on volume conduction and spatial RESOLUTION is dependent on the number of electrodes and their respective placement (see [Figure E.41](#)).



Figure E.41 Recording of skeletal muscle depolarization with electrodes placed on the skin, specifically the biceps.

Electron (e^-)

[atomic, energy, general, nuclear, solid-state] Atomic elementary PARTICLE, FERMION in the category of LEPTON. A negatively charged particle which is a constituent of every ATOM. Electrons are subject to the PAULI EXCLUSION PRINCIPLE due to their half-integer SPIN. The fermion nature forms the foundation of the atomic structure of atoms consisting of multiple electrons, which covers all ELEMENTS apart from hydrogen: ^1H (also see **E**).

Electron capture

[atomic, nuclear] Specific nuclear DECAY mode in which an orbital ELECTRON (e^-) is captured by the NUCLEUS as part of one of the options in a beta decay process with simultaneous emission of either a NEUTRINO or an antineutrino. Both the NEUTRINO (ν) and the ANTINEUTRINO ($\bar{\nu}$) were postulated by WOLFGANG PAULI (1900–1958) in 1931 to account for the energy balance in the decay process and the angular momentum conservation. The electron capture is favored by PROTON (p) rich nuclides, next to β^+ emission, while NEUTRON rich nuclides will predominantly have β^- emission. The process is schematically represented as: $p + \bar{e} \rightarrow n + \nu$.

Electron decay

[nuclear] See BETA DECAY.

Electron drift velocity

[electronics, general] Migration VELOCITY (v_e) of a single electron in a CONDUCTOR under the influence of the local temperature (T), the applied ELECTRIC FIELD (E) resulting from the POTENTIAL DIFFERENCE (V): $E = V/d$, applied over a DISTANCE d . Additional factors are the material composition, such as the electrical density (defined by the MOLAR MASS M and physical density ρ) and charge distribution within the conductor, defined by the equivalent RESISTANCE: resistivity ρ_R , temperature coefficient of resistivity α_T , the respective length over which the interaction takes place ℓ , and the number of free electrons that can potentially be released from the prevailing ATOM (the average electron release) f_e , expressed as $v_e = MV / (dN_a \ell e f_e \rho_R (1 + \alpha_T T))$, with Avogadro's number: $N_A = 6.022137 \times 10^{23}$ J/K and electron charge: $e = 1.60217657 \times 10^{-19}$ C (also see ELECTRIC CURRENT).

Electron energy state

[electromagnetism, energy, general, thermodynamics] The electron-binding states under atomic and molecular configurations under equilibrium conditions for a FLUID or solid are characteristic for the ISOLATED SYSTEM they belong to. The GROUND STATE energy configuration is generally sharp for a fluid, and relatively broadened on the outer shells for a solid. The respective energy states have associated WAVE functions that follows from the SCHRÖDINGER WAVE EQUATION. For solids, the energy configuration for crystalline structures is the most stable and most predictable, in contrast to the more amorphous energy band structure in glassy substances. The energy structure in crystals is considered an ordered solid where the Hamiltonian for the SCHRÖDINGER EQUATION ($H\Psi = E\Psi$) has periodic solutions $H(\vec{r} + \vec{R}_i) = H(\vec{r})$, with fundamental solutions $\Psi(\vec{k}, \vec{r}) = \Psi(\vec{r})e^{i\vec{k} \cdot \vec{R}_i}$, with $\vec{k}$ the wave vector for the virtual wavelength “ λ ” of the SOLUTION, considered a QUANTUM NUMBER for the electron in this case, partially governed by the Fermi–Dirac rules. For metals, the highest energy band (VALENCE BAND) provides a CONTINUUM with solutions $E_n(\vec{k}_F) = E_F$, where $\vec{k}_F$ is the Fermi energy wave factor and E_F the Fermi energy associated with the Fermi band of the electron distribution. The Gibbs energy equivalent (G) for the electron conglomerate filling the BRILLOUIN ZONE within the unit volume of a CELL outlining a single unit (i.e., ATOM or molecule: V_Ω) can be shown to satisfy $G(E) = (V_\Omega/4\pi^2)(m^*/\hbar^2)^{3/2} E^{1/2}$, with m^* being the effective mass for the grouping, $\hbar = h/2\pi$: where $\hbar = h/2\pi$, with $h = 6.626070040(81) \times 10^{-34}$ m²kg/s (Js) the Planck's constant, and all energy states in the Brillouin zone are equal: $E = E_n(\vec{k})$. The description of the energy configuration for a disordered system is complex and can be solved analytically only based on the Bloch theorem conditions. In case the periodicity is not presented, the system becomes ill-defined because the wavevector no longer has a sharp value. Chaotic systems such as alloys and heated liquids are not confined due to the free exchange of electrons between states and between systems.

Electron lens

[atomic, nuclear] Magnetic LENS used in ELECTRON MICROSCOPE to bend the path of electrons to achieve a focal irradiation (see [Figure E.42](#)).

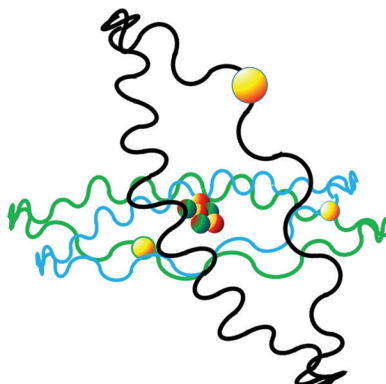


Figure E.42 Schrödinger wave electron energy orbital fit to energy band.

Electron microscope

[atomic, biomedical, imaging, nuclear] Imaging system that uses ballistic electrons (mass: $m_e = 9.10939 \times 10^{-31}$ kg; Electron charge: $e = -1.60217657 \times 10^{-19}$ C) in a VACUUM to engage in a SCATTERING interaction on a molecular level. Electrons are ELEMENTARY PARTICLES with NEGATIVE CHARGE discovered by JOSEPH JOHN THOMSON (1856–1940) in 1897 (for which he received the Nobel Prize in PHYSICS in 1906). These particles are composed from the CATHODE RAYS. Two specific elementary types of electron microscopy are available: transmission electron microscopy (TEM) and scanning reflection electron microscopy (SEM), with various versions. The electron microscope used the DE BROGLIE WAVELENGTH ($\lambda = h/p$, where PLANCK'S CONSTANT: $h = 6.626070040(81) \times 10^{-34}$ m²kg/s (Js), and $p = m_e v$ is the electron momentum, where m_e is the electron mass moving with velocity v , recognized by PRINCE LOUIS VICTOR PIERRE RAYMOND DUC DE BROGLIE [1892–1987] in 1924) of a fast moving electron to obtain high-resolution imaging based on the RAYLEIGH CRITERION: $D_{\text{res}} = D/1.22\lambda$, where D is the characteristic APERTURE of the imaging device. In 1927, Hans Busch (1884–1973) provided the theoretical evidence that electron beams can be focused by means of an inhomogeneous MAGNETIC FIELD. In his work, he described how the focal length of such a magnetic ELECTRON LENS could be continuously adjusted through adjustment of the coil current. In 1931, Ernst Ruska (1906–1988) and Max Knoll (1897–1969) constructed a magnetic lens, confirming the theoretical premise and continued to construct the first TEM instrument. In 1938, MANFRED VON ARDENNE (1907–1997) constructed a scanning TEM by adding additional coils that provide a steering mechanism to a TEM. In 1942, Vladimir Kosmo Zworykin (1889–1982), James Hillier (1915–2007), and R.L. Zinder (?–?) developed an electron microscope based on SCATTERING, primarily BACKSCATTER, eliminating the need for extremely thin samples. Backscatter describes the SEM. The scattering events result from the WAVE phenomenon according to the Bragg law describing the interaction with “planes” of atoms, which provides the relation between interplanar DISTANCE d and diffraction ANGLE θ as $n\lambda = 2d \sin \theta$. The wavelength of the electron beam is a direct result from the accelerating POTENTIAL DIFFERENCE (V) in the electron microscope, expressed as $\lambda = h/\sqrt{(2m_e e V)}$, where $h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck's constant. At the acceleration voltages used in TEM, relativistic effects have to be taken into account, providing: $\lambda = h/\sqrt{\{2m_e e V[1 + (Ev/(2m_e c^2))]\}}$, with $c = 2.99792458 \times 10^8$ m/s the speed of light. Just as a light MICROSCOPE, the electron microscope consists of a source collimators and lenses, and additionally

requires an detector system for the collection of the electron and subsequent processing for IMAGE reconstitution. The mechanism of operation is purely electronic/magnetic, in contrast to the GLASS/POLYMER lenses in an optical microscope. The control mechanism for the electrons is based on Lorentz force: $\vec{F} = -e(\vec{E} + \vec{v} \times \vec{B})$, where $\vec{B}$ represents the applied magnetic field and $\vec{E}$ is the electric field vector. Based on the inherent process of focusing the resolution (D_{res}) is described based on the electronic configuration of the objective “LENS” that can be defined by a device specific SPHERICAL ABERRATION constant (C_s) and a general NORMALIZATION constant A as: $D_{\text{res}} = AC_s^{1/4} \lambda^{3/4}$. The magnification attainable with SEM is in the order of 100,000 $\times$ and respectively for the TEM in excess of 1,000,000 $\times$ (compared to an effective magnification in the order of 1000 $\times$ with an optical microscope). Whereas an SEM primarily provides topographical information with RESOLUTION in the order of 10 nm, the TEM can show details about cellular composition, in biological imaging, with resolution better than 0.24 nm. The sample preparation requirements for TEM are much more strict than for SEM, down to 50 nm, whereas SEM can be used to observe intact animal specimen (see Table E.1).

Table E.1 Electron wavelengths at some acceleration voltages used in TEM

$V_{\text{acc}}[\text{kV}]$	B[PM]	A[PM]
100	3.86	3.70
200	2.73	2.51
300	2.23	1.97
400	1.93	1.64
1000	1.22	0.87

V_{acc} : accelerating voltage; A: non relativistic wavelength; B: relativistic wavelength.

The interaction process of the electron with the medium under investigation relies on several mechanisms of action (dominated by Coulomb forces), ranging from COMPTON SCATTERING to elastic and inelastically (consequence: increase in wavelength) scattered as well as AUGER ELECTRONS and gamma RADIATION emission, next to unscattered transmitted electrons. The gamma and X-RAY emission resulting from atomic and nuclear excitation can provide spectral information referring to the internal energy configuration. Factors influencing the electron penetration depth and the interrogated volume are the angle of incidence, the current MAGNITUDE and the accelerating voltage of the beam, next to the material properties such as the average ATOMIC NUMBER (Z) of the sample as well as the localized specific atomic number distribution. The excitation volume is punch-ball-shaped region with penetration ranging from 1 to 5 μm . Because of the potential for interaction of the electrons with any molecule or ATOM, electron microscopy generally needs to be performed under low to high VACUUM conditions. The imaging pressure ranges from 10^{-4} Pa to 10^{-9} Pa, while the electron gun may operate under 10^{-11} Pa, but can be as low as 10^{-7} Pa for modern microscopes. One aspect of electron microscopy imaging is sample preparation, making the “non-conductive” sample

susceptible to electron interaction. The sample preparation generally involves dehydration and coating with aluminum, gold, or silver (see [Figure E.43](#)).

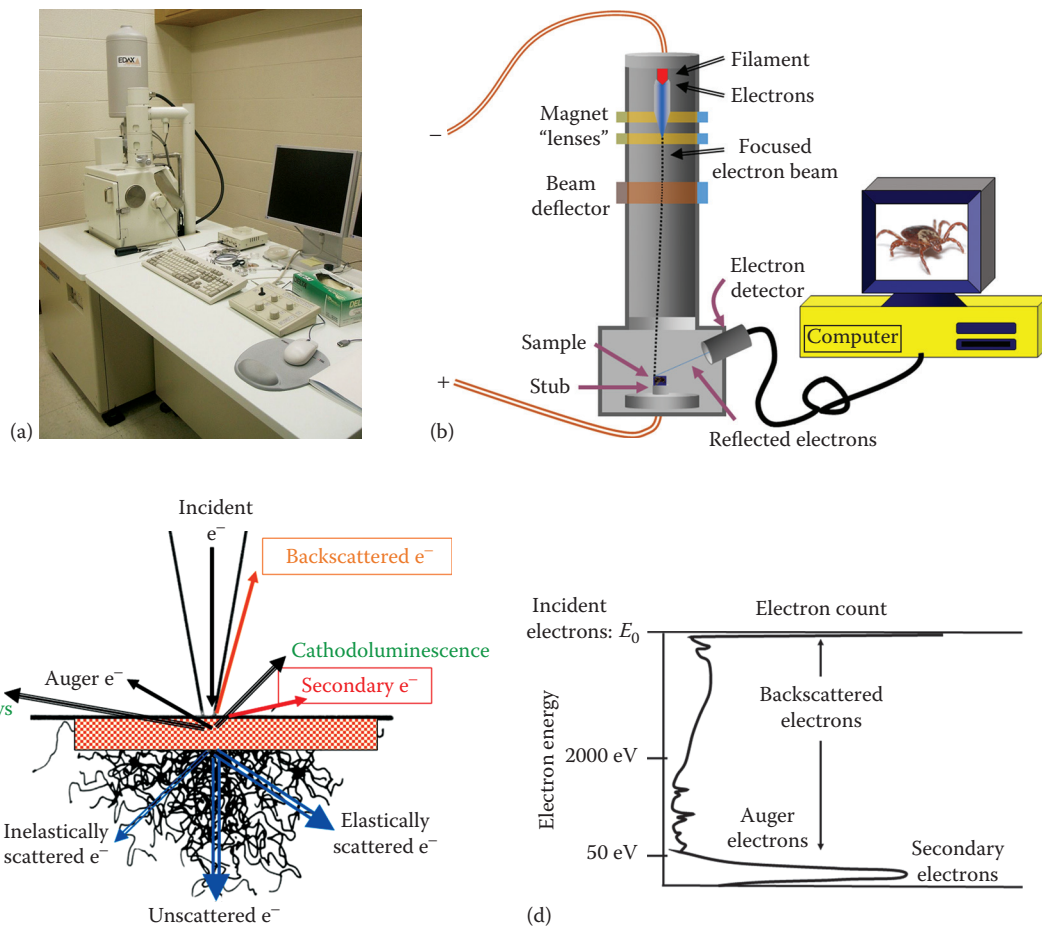


Figure E.43 (a) Diagram of the operation of a scanning electron microscope, (b) electron scattering distribution, (c) electron energy configuration, and (d) influence of surface contour on electron re-emission distribution.

Electron shells

[general] See **BOHR ATOMIC MODEL**.

Electron spin

[electromagnetism, energy, general, thermodynamics] Every electron has an associated **SPIN**, magnetic moment as well as mass and charge. The magnetic moment is defined with respect to the spin $\vec{s} = \hbar s$ for an electron with spin **QUANTUM NUMBER** s (a half-integer correlated to the angular momentum; note that particles with half spin are fermions and particles with whole integer spin are bosons) and where $\hbar = h/2\pi$,

which is PLANCK'S CONSTANT, $h = 6.626 \times 10^{-34}$ J/Hz divided by 2π as $\overline{\mu}_{\text{mag}} = -g_e \beta_m \vec{s}$, where $g_e = 2.0023$ the Landé factor, $\beta_m = \hbar |e| / 2m_e$ ($m_e = 9.10939 \times 10^{-31}$ kg the electron mass) the BOHR MAGNETON (see Figure E.44).

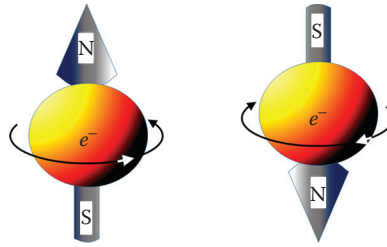


Figure E.44 The two possible electron spin configurations with $s = + (1/2)$ and $s = - (1/2)$.

Electron spin resonance

[electromagnetism, energy, general, thermodynamics] An electron can be placed in an external magnetic field with a steady-state value ($\vec{B}_0$) and a perturbation $\vec{B}$ (OSCILLATION). The steady-state magnetic field provides the “Zeeman energy” of the electron as: $W_Z = -\overline{\mu}_{\text{mag}} \cdot \vec{B}_0$, with the magnetic moment $\overline{\mu}_{\text{mag}} = -g_e \beta_m \vec{s}$, where $g_e = 2.0023$ the Landé factor or g -factor, $\beta_m = \hbar |e| / 2m_e$ ($m_e = 9.10939 \times 10^{-31}$ kg the electron mass) the BOHR MAGNETON, and $\vec{s} = \hbar \vec{s}$ the SPIN (in this case, specifically for an electron with spin QUANTUM NUMBER s and where $\hbar = h/2\pi$, which is PLANCK'S CONSTANT, $h = 6.626 \times 10^{-34}$ J/Hz divided by 2π). This situation has two stationary states: α , associated with the quantum number for the spin projection $m_s = +1/2$ and β , associated with the quantum number for the spin projection $m_s = -(1/2)$. The steady-state MAGNETIC FIELD induces PRECESSION with angular velocity: $\omega_0 = \gamma_e B_0$, where $\gamma_e = g_e |e| / 2m_e$ is the gyro-magnetic ratio. Under the influence of a homogenous magnetic field, the electrons will precess in PHASE. When a perturbation with fixed FREQUENCY ($\nu = (\omega/2\pi) = (c/\lambda)$, with wavelength λ and the speed of light: $c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-(1/2)} = 2.99792458 \times 10^8$ m/s) is applied with frequency ν_0 that matches the RESONANCE condition: $h\nu_0 = g_e \beta_m B_0$ the transitions between the α and the β state will flip in resonance.

Electron tube

[electromagnetism, energy, general, thermodynamics] It is the predecessor of the transistor. The VACUUM tube device was introduced by Thomas Alva Edison (1847–1931) in 1883 and was refined by SIR JOHN AMBROSE FLEMING (1849–1945) in 1904. The vacuum tube has an ANODE (+) and a CATHODE (–) as well as a set of conductive plates that can influence the migration of CATHODE RAYS. The original cathodes were filaments that emitted electrons on heating by means of passing a current through the filament. Several electron tubes (also known as “vacuum tubes”) were made to perform a variety of electronic functions, such as DIODE, triode, transistor, photo-multiplier, and a high-frequency triode (transistor equivalent) called the “pentode.” The triode has gain (amplification) that results for the effective internal electronic configuration with an equivalent circuit representing induction, RESISTANCE, and capacitance. The PHOTOMULTIPLIER TUBE is also referred to as “photocell” or “photoemissive tube,” which uses the ELECTRODE work function in response to external electromagnetic irradiation to induce a current that provides the means to quantify the radiance incident on the tube.

Electron volt (eV)

[general] It is the amount of energy gained by an electron charge (either positive or negative) in passing through a potential difference of 1 V.

Electron wake

[atomic, nuclear] Variations in electron density for the free-electron distribution in a CONDUCTOR, semiconductor as well as INSULATOR after the passage of an ION with charge (Ze) traveling with high VELOCITY (v) through the SOLID-STATE medium (CONDENSED MATTER). The WAKE will be formed with a spatial resonant frequency (ω) with spatial period: $d = 2\pi v/\omega_0$, also known as the "WAVELENGTH" (λ). The local AMPLITUDE of the wake OSCILLATION has a maximum just within half a wavelength from the trajectory amounting to: $V_{\max} = Ze(\omega_0/4\epsilon_0 v)$, rapidly dampened by INELASTIC COLLISIONS of charges. The amplitude of the wake reduces to e^{-1} within 10λ behind the traveling ion and laterally $r_{e-1} = v/\omega_0$. For conducting media the resonant frequency (ω_0) is the PLASMA FREQUENCY of the METAL: $\omega_p = \sqrt{(\rho_{e,0}e^2/\epsilon_0 m'_e)}$, with $\rho_{e,0}$ the electron density, $e = 1.60217657 \times 10^{-19}$ C the electron charge, m'_e the effective electron mass, and $\epsilon_0 = 8.85419 \times 10^{-12}$ C²/Nm² the permittivity of free space. At speeds greater than the Bohr speed (i.e., $v_M = 2.2 \times 10^6$ m/s, which is the velocity of an electron in the hydrogen GROUND STATE in the Bohr model) the atoms in the path are stripped of their VALENCE electrons, thus corresponding to an equivalent Mach speed. Under these conditions, the created ions are freely migrating. The ion wake formed under these conditions is subject to INTERFERENCE of traveling ion clusters. The Coulomb forces between the heavy ions creates conditions that support collisions and an "explosion" will be effected (known as a "Coulomb explosion"). In analog-to-fluid dynamic principles the ion will also generate a "bow" WAVE of electrons in front of the ion location, spreading radially from the ion location on the trajectory.

Electronegativity

[atom, chemical, general, solid-state] The ability of a molecular ATOM to attract electrons and bind to them. This phenomenon was introduced by LINUS CARL PAULING (1901–1994) in 1932. The electronegativity is a relative indication of the electron attraction within the molecule. The electronegativity is considered between two atoms and is a function of the intermolecular bonds (strong bonding within the respective atoms) and intramolecular bonds (covalent binding between atoms 1 and 2). The bonding energy is measured by dissociation energy (E_d ; measured in eV) for the respective attractions. The difference in electronegativity between $atom_1$ (χ_1) and $atom_2$ (χ_2) is defined as the weighted average for all chemical bonds as: $\chi_1 - \chi_2 = C \sqrt{(E_{d,12} - ([E_{d,11} + E_{d,22}]/2))}$, where C is a unit NORMALIZATION constant. Fluorine is the most electronegative ELEMENT (3.98 on the Pauling electronegativity scale). The definition was later refined by Robert Sanderson Mulliken (1896–1986). In 1934, Robert Mulliken suggested the use of IONIZATION ENERGY (E_i) and electron affinity (E_{ca}) for a single element, hence defining an absolute scale: $\chi = (E_{ca} + E_i)/2$. The final revision was made in 1989 by Leland Cullen Allen (1926–2012) using the VALENCE energy of the free electrons in the respective element using the one-electron s - and p -energy for the isolated atom (ϵ_s and ϵ_p) and the respective number of electrons in either state (n_s and n_p): $\chi = c'((n_s \epsilon_s + n_p \epsilon_p)/(n_s + n_p))$, where c' is a normalization scaling factor (energies expressed in J vs. eV).

Electronics

[electromagnetism, energy, general, thermodynamics] Configuration of devices based on components that can manipulate the MAGNITUDE and frequency (spectrum) of electron currents. Electronics provides the basis for the production of test and MEASUREMENT devices as well as television and RADIO. Electronics uses

components ranging from resistors, capacitors, and inductors to transistors and INTEGRATED CIRCUITS. Electronics may involve the specific design of a device, the operating conditions and output parameters versus input parameter requirements as well as designing a complex diagram connecting multiple components on a circuit to provide a specific outcome based on the available input parameter and conditions (see Figure E.45).

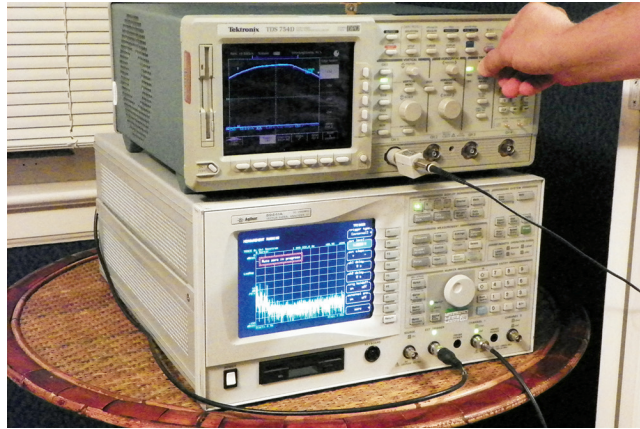


Figure E.45 Example of electronics: oscilloscope (top) and electromagnetic field spectrum analyzer (bottom).

Electro-optical effect

[electromagnetism, energy, general, thermodynamics] See **Kerr effect**.

Electrophysiology

[biomedical, chemical, electronics] The biological functionality associated with cellular function. Specific functions are the excitation and contraction process for the HEART muscle, nerve excitation and propagation, and SKELETAL MUSCLE coordination and contraction, next to brain ACTIVITY and a broad range of chemical and electronic processes in the human and animal body that can be measured with scientific tools, quantified, and theoretically modeled. The electrical, chemical, and physiological functions associated with these functions range from a single cellular MEMBRANE function to intercellular and intracellular communications and conduction and anatomical composition. In most cases, the data recording will need to be performed noninvasively to preserve the integrity of the phenomenon and to avoid interfering with the biological and physical responses. The measured data can be used to TRACE back the anatomical origin of certain signals and the initiations source process. The diagnostic mechanism and the theoretical analysis can provide valuable information about the source of a deviation in the anticipated biological system; taking into account that the biological system is an integral system, all factors are communicating with each other and subsequently influence each other. One striking example is the fright and flight response where a sensory input (e.g., flash or light, LOAD NOISE) is converted in a chemical release (e.g., adrenaline) followed by a range of activities that assist in a removal from suspected harm. Those activities may include an increase in heart rate, increased VENTILATION rate, skeletal muscle contraction, and enhanced sensory attention (supposed redirection of the emphasis of brain activity). Examples are the recording of the ECG, EMG, EEG, as well as specific functional SIGNAL acquisition such as VISION, HEARING, touch, smell, and taste; for animals with

special sensory devices, the range extends to MEASUREMENT of the muscle contraction of a potential prey (e.g., SHARK) (*also see* VOLUME CONDUCTION) (see [Figure E.46](#)).



Figure E.46 Electrophysiologic monitoring of heart rate (ECG), respiration rate, blood oxygenation, brain function (EEG), and additional vital signs at the bed side of a patient.

Electroscope

[atomic, general, nuclear] Device used to visualize the ELECTRIC CHARGE content on a device either by POLARIZATION or by charge transfer. Generally, the device consist of a VACUUM chamber with a movable leaf that is in static and dynamic equilibrium and can move freely around a central axis. Once electric charge is applied, the leaf and the fixed counterpart plate are charged with the same charge and will create a repulse force between the like charged panels, forcing the leaf on the axis to turn away from its counterpart, also found as “electrometer” (see [Figure E.47](#)).



Figure E.47 Electrostatic voltmeter used to provide indication of static charge on a device by touching it with the electrode from the electrostatic voltmeter.

Electrostatic field

[electronics, general] Electric field line density terminating on or merging from an ELECTRIC CHARGE distribution. The electrostatic field is stationary and steady-state and obeys Coulomb's law $E_e = Q/4\pi\epsilon r^2$, with Q being the total charge assembled in a point of reference, where outside the charge distribution, the charge may be considered in the center of the system, measuring the DISTANCE as the radius from the center r and $\epsilon = \epsilon_r\epsilon_0$, with ϵ_r being the material constant RELATIVE PERMITTIVITY and $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space. The field inside the charge CARRIER will be zero for a CONDUCTOR. For an INSULATOR, the field changes with the volumetric charge distribution and follows from GAUSS'S LAW, calculating the electric FLUX through the surface enclosed up to the point of interest. The charge is now expressed as the VOLUME CHARGE DENSITY (ρ_e ; for a sphere with radius R : $\rho_e = Q/((4/3)\pi R^3)$, assuming a homogeneous charge distribution), with respect to the point of interest at location r ($r \leq R$) from the center of the charge distribution. The electric field in the insulator is now: $E_e = Qr/4\pi\epsilon R^3$,

keeping in mind that the charge outside the GAUSSIAN SURFACE does not provide in inward electric field. Note that at the boundary this reverts to the original electric field postulated by CHARLES-AUGUSTIN DE COULOMB (1736–1806) (see [Figure E.48](#)).

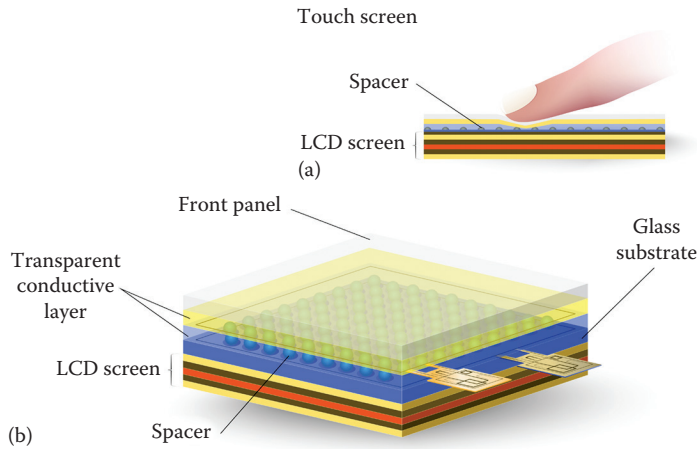


Figure E.48 Illustrations of two kinds of static electric field configurations: (a) touch screen that relies on capacitive charge for on/off commands and (b) the formation of lightning by means of the build-up of a static electric field between the clouds and the Earth's surface, alternatively between respective clouds.

Electrostatic force

[electromagnetism, general] A force between two static and steady-state charges q_1 and q_2 respectively at a separation DISTANCE r : expressed as: $F_e = q_1 q_2 / 4\pi\epsilon r^2 = q_2 E_e$, where $\epsilon = \epsilon_r \epsilon_0$, with ϵ_r the material constant RELATIVE PERMITTIVITY and: $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2 / \text{Nm}^2$ the permittivity of free space, E_e the electric field (see ELECTRIC FORCE).

Electrostatic generator

[general] See VAN DER GRAAFF GENERATOR and TESLA COIL.

Electrostatics

[electromagnetism, energy, general, thermodynamics] A field of science and ENGINEERING dealing with the effects of steady-state charge distributions, involving positive and NEGATIVE CHARGE configurations. All phenomena can be described by coulomb fields and coulomb forces. Static ELECTRICITY forms a special case in electrostatics. The branch of electricity science that applies to objects and electrical phenomena at rest, in contrast to ELECTRODYNAMICS. Static electricity is one of the most well-known examples of electricity at rest.

Electrostriction

[thermodynamics] A decrease in volume associated with an increase in electric field strength in a specific regional volume within a thermodynamic system volume operating at constant temperature. The Gibbs energy (G) for the confined volume (V_c) within the larger volume (V) is expressed as: $G = U - TS + PV - V_c \epsilon^* \mathcal{E}^2$, where U is the internal energy, S is the entropy of the system, P is the pressure, $\mathcal{E}$ is the uniform ELECTROSTATIC FIELD strength in the volume V_c and $\epsilon^* = \epsilon^*(T, P)$ the DIELECTRIC constant in the volume. For a system with n constituents and in this geometry and with the specified configuration, the following two conditions apply illustrating the electrostriction phenomenon: $(\partial S / \partial \mathcal{E})_{T, P, V_c, n} = 2\mathcal{E} V_c (d\epsilon^* / dT)_P$ and $(\partial V / \partial \mathcal{E})_{T, P, V_c, n} = -2\mathcal{E} V_c (d\epsilon^* / dT)_T$.

Electrotonic length (λ_ℓ)

[biomedical, electromagnetism] In a myelinated nerve CELL (axon), this is the length covered by a Schwann cell in electronic definition. Over this length, no ION exchange is possible due to the insulation and hence has no local action-potential: $\lambda_\ell = \sqrt{r_1^2 \pi R_m / 2\pi r_1 R_\ell} = \sqrt{r_1 R_m / 2R_\ell}$, with r_1 being the radius of the axon, R_m the MEMBRANE resistance, and R_ℓ the linear conductive RESISTANCE over the length of the Schwann cell. Because in a MYELINATED NERVE cell, the SIGNAL “jumps” from NODE OF RANVIER to another node of Ranvier over the segment covered by the Schwann cell the DEPOLARIZATION potential needs to be larger for long electrotonic length than for a short electrotonic length (e.g., unmyelinated axon) to sustain the depolarization to be carried over the long segment through conduction instead of depolarization. Note that resistive conduction is a passive process and is lossy, whereas depolarization is an active process and is lossless. The determination of the depolarization potential and the electrotonic length is an important factor when considering multiple sclerosis, which destroys the myelin.

Electroweak epoch

[astronomy/astrophysics, general, quantum] A time frame in the period from 10^{-34} to 10^{-11} s after “Genesis” in the Big Bang creation of the UNIVERSE playbook where the universe “consisted” in a small volume with only leptons, bosons photons, quarks, vector bosons, and gluons, and the interaction was dominated by the ELECTROWEAK FORCE under an approximate temperature of 3×10^{15} K. As the universe cooled, the electroweak force diminished, the vector bosons acquired mass, and the FOUR FORCES became the ruling interaction: GRAVITY, WEAK FORCE, electromagnetic force, and strong force. Note that the vector bosons W^- , W^+ , and Z^0 were experimentally verified in 1983.

Electroweak field

[general] Convolved merger of the “weak” force and ELECTROMAGNETIC FIELD (*also see* HIGGS FIELD).

Electroweak force

[general, high-energy] Force structure based on the nonrenormalizable WEAK INTERACTION theory of ENRICO FERMI (1901–1954), postulated in 1932. The neutron DECAY defined under this needed additional details, which was added by HIDEKI YUKAWA (1907–1981), a theoretical physicist from Japan in 1934, introducing a “messenger particle.” The physicist Julian Seymour Schwinger (1918–1994) from the United States introduced the W-vector bosons as the representative messenger PARTICLE in 1956 under the developing GAUGE THEORY. The electroweak force defines the interaction between quarks, by definition,

transforming the “flavor” without changing the “COLOR.” The WEAK FORCE depends on the handedness of the particles involved in the interaction process as well as the alignment, antialignment of the linear momentum and SPIN angular momentum for the fermions, and quarks and leptons involved.

Electroweak theory

[general] QUANTUM gauge theoretical incorporating four-gauge QUANTA; the vector bosons W^- , W^+ , Z^0 as well as the forth massless force CARRIER the PHOTON. This theory was designed by SHELDON LEE GLASHOW (1932–), a physicist from the United States, STEVEN WEINBERG (1933–), a scientist from the United States, and Abdus Salam (1926–1996), a physicist from Pakistan (initially working independently but merging thoughts; he shared the Nobel Prize in PHYSICS on this), based on the work of Gerhard van't Hooft (1947–), a graduate student from the Netherlands, with respect to the Yang-Mills gauge fields performed in 1969. The unified force acts between leptons and between hadrons over an effective range in the order of 10^{-17} m. The electroweak theory combines the “WEAK FORCE” and the “electromagnetic force.” The vector bosons have three CHARM conditions (–1, 0, and 1) also referred to as ν , μ , and τ (see GAUGE THEORY). The gauge is the phenomenon part of the interaction and is defined by $\mathcal{L}_{\text{gauge}} = -(1/4)F_{\mu\nu}^i F^{\mu\nu i} - (1/4)B_{\mu\nu} B^{\mu\nu}$, where $i = 1, 2, 3$, with the field strength tensors defined by the respective “MAGNITUDE” (“ $W_{kk}^{\parallel}$ ”) “PHASE” (“ $B_{ij}^{\parallel}$ ”) as $F_{\mu\nu}^i = \partial_\mu W_\nu^i - \partial_\nu W_\mu^i + g^* \epsilon_{ijk} W_\mu^j W_\nu^k$ ($j, k = 1, 2, 3 \dots$), with W_{ij}^{∞} representative of the “weak force,” g^* the gauge-coupling coefficient for condition $SU(2)U(1)$ linking the “phases” W^0 of the W vector bosons to the “phases” for B in gauge classification $U(1)$ as referenced by the weak neutral current: $\mathcal{L}_{SU(2) \times U(1)} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_\phi + \mathcal{L}_f + \mathcal{L}_{\text{Yukawa}}$, ϵ_{ijk} a symbol that provide total asymmetry in the gauge configuration, and $B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$.

Element

[atomic, chemical, energy, quantum] A pure substance consisting of ATOMS of the same ATOMIC NUMBER, which cannot be subdivided by ordinary chemical means. The designation “element” was introduced in 1661 by ROBERT BOYLE (1627–1691). Evidence leading to the definition of an element was based on the work by JOHN DALTON (1766–1844), who postulated the first CHEMICAL REACTION statement in 1808, including that every pure CHEMICAL is made up of same elementary components, forming the element foundation. The ELEMENTS themselves were also considered to be composed of a unique grouping of identical components, being atoms. Additional work in this field was made by AMEDEO AVOGADRO (1776–1856) in 1811, who concluded that not all elements consist of single atoms, some are biatomic (i.e., MOLECULES), which provided supporting evidence with regard to the chemical mass statements made by Dalton (see Figure E.49).



Figure E.49 Example of one outline for the periodic table of elements. (Copyright 2007–2012 Jeff Bigler.)

Elemental species

[chemical, thermodynamics] The complete set of independent ingredients of a chemical reaction. The respective independent constituents become involved in a reaction that conforms to the conservation of atomic nuclei and new constituents can, and will be formed during the reaction process (i.e., product), while the reaction cannot consist of only the primary constituents. An elemental species by definition is formed from a single group of atomic nuclei and the molecular structures formed during the reaction are the most stable kind. All process are considered at normal temperature ($T = 25^\circ\text{C}$) and pressure ($P_0 = 1\text{atm} = 1.01325 \times 10^5\text{ Pa}$).

E

Elementary particles

[atomic, electromagnetism, energy, general, high-energy, nuclear, solid-state, thermodynamics] Building blocks of atomic PHYSICS, with a subdivision to particles smaller than the electron, PROTON, and NEUTRON. The elementary particles are divided in leptons and hadrons. The leptons have two specific pairs: the ELECTRON (e^-)–electron-NEUTRINO (ν_e) pair and the MUON (μ^-)–muon-neutrino (ν_μ) pair, respectively. The following categorical discrimination in elementary particles can be made: first, second, and third generation elementary particles, which are subdivided in quarks, leptons, and HADRONS. The detailed subdivision is accordingly arranged per group. Hadrons are further subdivided in mesons and BARYONS. The mesons consist of PION and KAON particles, whereas the baryons are made up of the following: lambda (Λ^0), neutron (n), omega (Ω^-), proton (p), sigma (Σ^+ , Σ^0 , and Σ^-), and xi units (Ξ^0 and Ξ^-). Leptons have the following constituents: electron (e^-), muon (μ), NEUTRINO (e , ν_e ; μ , ν_μ ; τ , ν_τ), and tau (τ) entities. In turn, all particles also have a so-called anti-particle (see HADRON and LEPTON).

Elements

[general, nuclear] A chemical ELEMENT is an elementary material with specific unique physical and chemical properties that are equal to the homogeneous substance consisting of a single element. The element is labeled by a single atomic constituent. All known elements are grouped in the PERIODIC TABLE OF ELEMENTS. At standard conditions, elements can be LIQUID, solid, or GAS. There are several classifications of elements, ranging from metals, metalloids, and nonmetals, to a more detailed groping in families of: alkali EARTH, alkaline Earth, transition METAL, rare Earth, other metal, metalloid, and nonmetal halogen to NOBLE GAS.

Ellis, Charles Drummond (1895–1980)

[general, nuclear] A scientist from Great Britain who designed a micro-calorimeter in 1927 in order to establish the energy exchange with respect to the NEUTRINO and beta DECAY for radium E decaying to polonium, and showed the potential for fundamental PARTICLE validation; however, he failed in the initial attempt. Nevertheless, the initial failure lead to the discovery of the neutrino based on the apparent energy loss. In 1933, WOLFGANG PAULI (1900–1958) suggested the new neutrino as the source of the missing energy, which as later identified by LISE MEITNER (1878–1968) during her repeated experiment in 1957. Charles Ellis' collaborator was WILLIAM ALFRED (PETER) WOOSTER (1903–1984) (see Figure E.50).

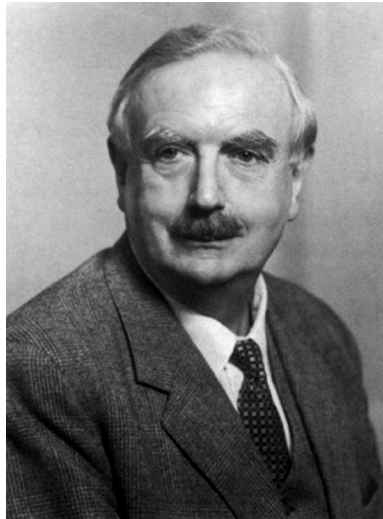


Figure E.50 Charles Drummond Ellis (1895–1980). (Courtesy <http://nuclphys.sinp.msu.ru/>.)

Elster, Julius Johann Phillipp Ludwig (1854–1920)

[geophysics, nuclear] A physicist from Germany. The work of Julius Elster involved the investigation of atmospheric ELECTRICITY phenomena and ionizing RADIATION. Julius Elster invented the photocell in collaboration with HANS FRIEDRICH GEITEL (1855–1923) in 1893 (see [Figure E.51](#)).



Figure E.51 Julius Johann Phillipp Ludwig Elster (1854–1920) and Hans Friedrich Geitel (1855–1923). (Courtesy Museum im Schloss Wolfenbüttel.)

Elster and Geitel experiment

[atomic, nuclear, quantum] Experimental verification of the theoretical description of electrification of RAIN drops by JULIUS JOHANN PHILLIPP LUDWIG ELSTER (1854–1920) and HANS FRIEDRICH GEITEL (1855–1923) in 1900. This work supported the novel general concepts of QUANTUM THEORY. Additional conclusions about RADIOACTIVITY could be derived from this work in the early stages of the discovery of radioactivity.

Embolism

[biomedical, fluid dynamics] Obstruction in the FLOW, particularly in BLOOD vessels. In MEDICINE, an EMBOLISM can be a blood clot, fat, plaque, or a BUBBLE that is formed rather abruptly. One form is the release of an AIR bubble (either during clinical procedures or as a result of the quick release of gasses from

the vessel WALL under CAISSON DISEASE) that becomes trapped in a narrow diameter blood vessel, a part of thrombus, or plaque that becomes dislodged and occludes a distal vessel (see [Figure E.52](#)).

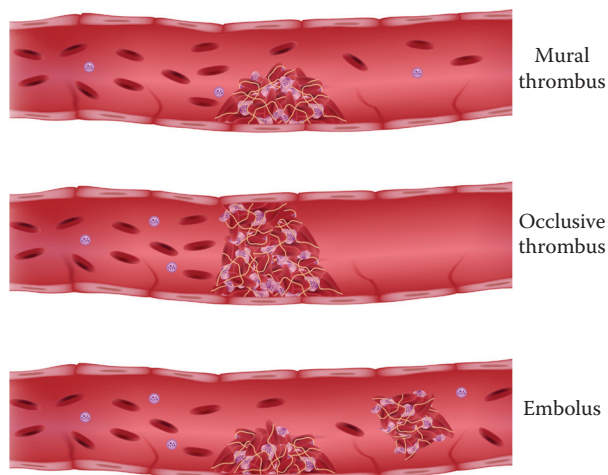


Figure E.52 An embolism in a blood vessel.

Emission coefficient

[general] The emitted radiance from an object within a narrow wavelength bandwidth indicating the ability of a body to emit RADIATION as a fractional reference. A perfect emitter will have an emission coefficient $\epsilon_\lambda = 1$.

Emission spectrum

[general, optics] The optical emission over a broad range of wavelengths from an excited GAS. The emission lines are representative of specific atomic transitions and can hence be used to identify the constituents as well as the energy configuration, such as the influence of neighboring atoms and molecules (see [Figure E.53](#)).

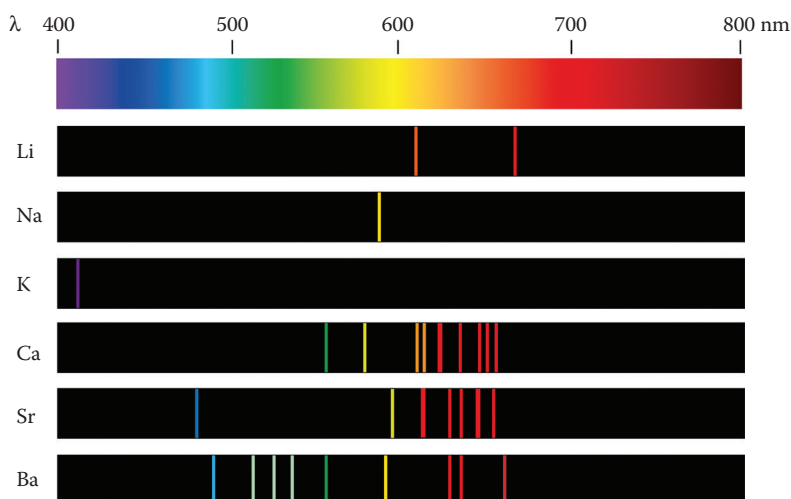


Figure E.53 Emission spectra in the visible range for several elements: lithium (Li), sodium (Na), potassium (K), calcium (Ca), strontium (Sr), and barium (Ba).

Emission theory

[general] Conceptual interpretation of light as a stream of infinitely small particles. Under this premise, the EYE emits light and captures that same beam of particles that is reflected from the objects in sight, documented as proposed by the Greek philosopher, mathematician, and scientist Plato (427–347 BC). The emission theory provided a plausible explanation for REFLECTION. It is also known as the “theory of extramission,” where the eye emits a “probing beam” without external light. The EXTRAMISSIION could however not account for the lack of VISION at night. The first attempt to discredit the emission theory or extramission was by ARISTOTLE (384–322 BC).

Emissivity

[atomic, energy, nuclear, optics] Emission ability relative to a BLACK BODY at the same TEMPERATURE (T) as a function of WAVELENGTH (λ) expressed as a fraction: $0 \leq \epsilon_{\lambda}(T) \leq 1$. The emissivity relates to the Kirchhoff law introduced in 1859 (*also see* BLACK BODY RADIATION).

Empirical valence bond (EVB)

[biomedical, chemical, general, nuclear, thermodynamics] In biological systems, the conversion processes between various forms of energy often take place on an atomic level. One form in particular converts PHOTON energy into CHEMICAL ENERGY, for cellular consumption, specifically involving BACTERIORHODOPSIN (*also see* PN-JUNCTION, TRANSISTOR, MECHANONSENSITIVE ACTION, and MEMBRANE).

Endergonic process

[thermodynamics] A process where the energy of the initial state is lower than the energy of the final state, also known as “endoergic process.”

Endocytosis

[biomedical, chemical] The active process of cellular consumption of both solid and LIQUID material, defined as PHAGOCYTOSIS (eating) and PINOCYTOSIS (drinking) next to TRANSCYTOSIS for large molecule transport. The CELL MEMBRANE forms an enclosure (vesicle) that engulfs the material of interest for consumption and transports the filled “BUBBLE” through the cell MEMBRANE. The vacuole will open (by means of chemical breakdown) once inside the cell to release the content or will be transported through the cell for release as a whole enclosure outside the cell intended for consumption by other cells. The other processes available for ingestion are attachment of molecules in specifically designed transmembrane pores that offer selective attachment to fatty substances (lipid, providing lipophilic transport mechanism) and WATER (hydrophilic molecules, loosely attaching to the water molecules for subsequent release under changing polarity resulting from chemical conditions, which are different in the intercellular environment from the extracellular milieu). The LIGAND gated channels providing molecular transport form a selective mechanism of chemical exchange. The transport of the lipophilic and hydrophilic molecules with LOAD attached, is primarily facilitated through chemical and electrical gradients across the cell membrane (e.g., facilitated DIFFUSION). Endocytosis also plays an important role in neural transmission in the space of a SYNAPSE (synaptic cleft), linking one or more nerve cell from axon to dendrite(s). The cellular membrane as well as intracellular organelles are composed of lipids and proteins arranged in a dynamic lipid bilayer. The term “dynamic” means that it can actively adjust to external conditions (e.g., stress and strain) as well as actively

form a segment of bilayer that has a specific function (*also see* CELL MEMBRANE). Endocytosis is complemented by EXOCYTOSIS for the removal from the cell (see [Figure E.54](#)).

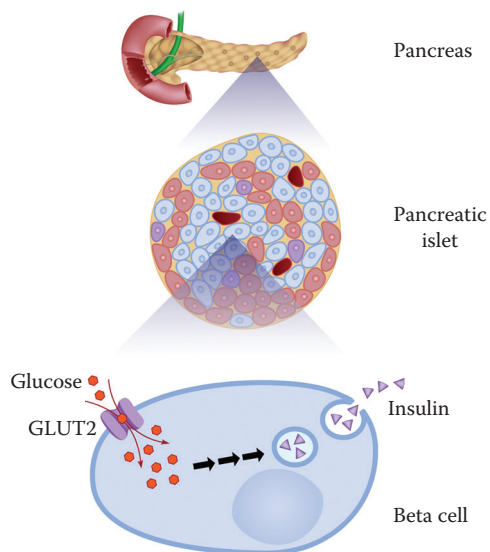


Figure E.54 The process of endocytosis highlighted by means of cartoon interpretations of the chemical and mechanical interactions at the cellular membrane.

Endoergic reaction

[atomic, chemical, condensed matter, nuclear] A reaction that absorbs energy. A process with a net positive change in Gibbs energy, specifically referring to nuclear reactions that absorb energy, also found as endergonic reaction.

Endoscope

[biomedical, general, optics] An optical device constructed with fiber-optics or LIGHT GUIDE to be introduced into the HUMAN BODY for examination of internal structures of organs (see [Figure E.55](#)).

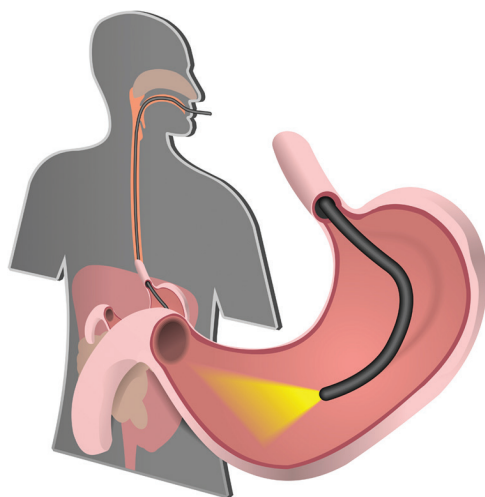


Figure E.55 Illustrations of an endoscopic examination.

Endothermic process

[atomic, nuclear, thermodynamics] Chemical or thermodynamic process that requires the addition of heat in order for the process to initiate and proceed. One specific example of an endothermic process is vaporization (see [Figure E.56](#)).



Figure E.56 Example of endothermic process. The electrically powered nicotine distribution in the electronic cigarette with turbulent smoke (vapor).

End-point energy

[atomic, nuclear] Energy content of a system at the termination of nuclear DECAY. The endpoint energy is defined as the difference in energy between the initial and the final states.

Endurance

[biomedical, general, mechanics, solid-state] In biomedical applications, endurance refers to the ability to sustain a certain level of ACTIVITY, for example, running. In material science, endurance refers to the resilience of a material to repeated exposure to stress and strain. In both cases, the end result is FATIGUE, either MUSCLE fatigue or material failure. In material failure, there will be crack formation, which can be captured as a the growth of the length of the crack ℓ_c , which is a function of the applied stress. The crack propagation under the influence of repetitive stress is defined as $d\ell_c/d\omega_N = C_{\text{mat}}K_F^n$, with ω_N being the total number of stress cycles, C_{mat} a material constant (found in a tabulated form for the final configuration of the material as used in analysis for the strength of materials and the planning for final requirements of the end-product composition), $K_F \cong S_\sigma \sqrt{(\pi \ell_c)}$ the intensity factor of the cyclic stress, S_σ the peak MAGNITUDE of stress (the AMPLITUDE of the harmonic stress function), and n a proportionality factor that ranges from 2 to 6, generally 4. This expression of crack propagation is known as the “Paris equation.” The number of cycles required to reach failure is expressed by the Coffin–Manson law as a function of the plastic strain AMPLITUDE: $\epsilon_p = \epsilon_s - \epsilon_e$, where ϵ_e is the elastic strain, where failure limit due to repetitive MOTION is expressed as $\omega_N^q = C_p/\epsilon_p$,

with $C_p \cong \epsilon_{sf}/2$ a material constant, with ϵ_{sf} the PLASTIC STRAIN at failure under static LOAD, and q a procedural constant, generally $q = 1/2$, under the condition $\epsilon_p \gg \epsilon_s$ (see Figure E.57).



Figure E.57 Example of physical endurance during mountain climbing.

Energetics of fission

[nuclear] In NUCLEAR FISSION, the NUCLEUS will be broken down into smaller size, and lighter, nuclei. The difference in mass between the initial composition of the PARENT NUCLEUS “P” and the end-product DECAY siblings “S” can be expressed in a relativistic energy balance providing the energy release during FISSION using $E = mc^2$, with m being the mass of the respective component and c the speed of light with respect to the reaction process: ${}_b^aP' + \text{instigator} \rightarrow {}_d^eS'_1 + {}_f^gS'_2 + \text{radiation} + \text{elementary particle} + \text{energy}$ (see Figure E.58).

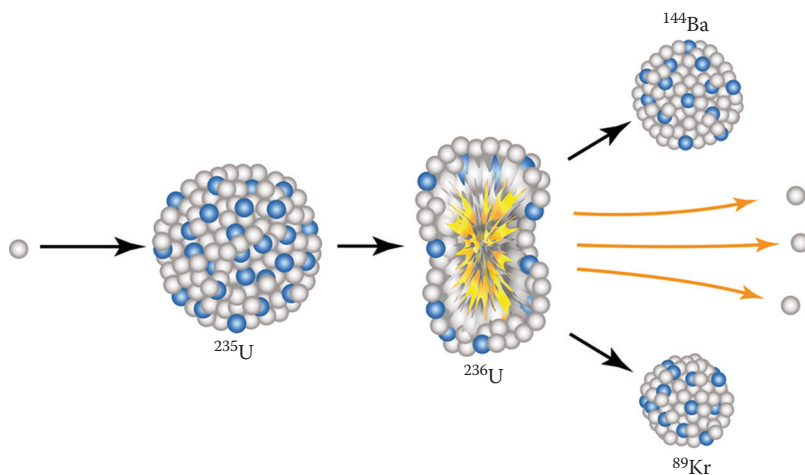


Figure E.58 Fission process with particle product.

Energy

[biomedical, nuclear, thermodynamics] The term was introduced by Thomas Young (1773–1829) in 1807 and was applied to thermodynamic principles postulated by Lord Kelvin (1824–1907) in 1852. Energy is defined as the ability of an object to perform work. Energy can either be supplied or taken away from the system in order for the processes, as well as changes in processes, to occur, and is the capacity for doing work. Potential energy is the energy inherent in a body because of its position with reference to other bodies.

Kinetic energy is the energy possessed by a mass because of its MOTION. The energy transferred into the system or released by the system is called “work.” Energy is required to sustain all forms of ACTIVITY, including life in all its forms. One of the most well-known and most powerful natural sources of energy for the EARTH is the SUN. The amount of energy that reaches the Earth’s surface is 1366 W/m^2 , which represents ELECTROMAGNETIC RADIATION of all wavelengths irradiated by the Sun. This energy is used to sustain activity (both chemical and molecular) as well as life in every aspect. One specific example of the contribution of energy to life and chemistry is in PHOTOSYNTHESIS in plants, where visible light is essential in the conversion of carbon dioxide to oxygen; other examples are in activation of the photosensitive cells in the EYE, next to the regulation of the circadian cycle by the hypothalamus. Energy is also used for powering biometric communications such as electrical SIGNAL conduction and neurotransmitter release in nerve cells, and on a MICROSCOPIC scale, the importing/exporting and processing ions and molecules in cells. Energy is stored in biological cells in a similar fashion as in a BATTERY (potential energy) in the form of bonds between chemicals, in biology the phosphate groups in the ADENOSINE TRIPHOSPHATE (ATP) molecule. When the ATP bonds are broken and phosphor is released (forming ADENOSINE DIPHOSPHATE [ADP]), energy is made available for other endergonic (energy gaining) reactions in the CELL and HOMEOSTASIS (see Figure E.59).



Figure E.59 Collage of various energy resources.

Energy, internal

[thermodynamics] Introduced by Rudolf Clausius and William Rankine in the late 1800s, replacing “internal work” and “inner work” as thermodynamic indicators of molecular ACTIVITY in THERMODYNAMICS.

Energy bands in solids

[atomic] In comparison to a GAS where the individual atoms have their own respective energetic configuration; in a solid, the atoms will be closely separated providing an opportunity to share low-energy external electrons. The sharing of electron across atoms in a solid results in an energy split. The energy split results in energy band configuration for the solid instead of energy levels as found in the GAS PHASE. The WAVE functions for the energy band (known as the transition from the VALENCE BAND to the CONDUCTION BAND in conductors) will permeate across neighboring atoms, essentially filling the entire sample. For insulators, the energy gap to the energy band above the filled single-atom atomic band is too great to allow for transitions to the sharing state of electrons, leaving the conduction band unoccupied. In semiconductor, the valence band and conduction band are widely separated, but the external influences of thermal or electronic energy can bring electrons in the shared state conduction band.

Energy conservation

[general] See CONSERVATION OF ENERGY.

Engine

[mechanics, thermodynamics] Device designed to perform work, generally by means of artificial source of energy, above and beyond human MUSCLE power. Several types of engines have been designed and developed of the centuries with a variety of energy sources used to provide the mechanism of operation. Examples of engines are Steam engine, combustion engine (internal and external), JET engine, electric engine (electric MOTOR), wind-powered engine, spring-action (e.g., clocks made between the early fifteenth and twentieth century, mainly replaced by ELECTRONICS in the twenty-first century), hydropower, SOLAR POWER, NUCLEAR FISSION and nuclear FUSION, and refrigeration to name but a few. Engines can be described by various processes that are specific to the mechanism and operation. Examples of thermodynamic models are the CARNOT CYCLE, the Rankin cycle, the OTTO CYCLE, the DIESEL CYCLE, the JOULE-BRAYTON CYCLE, the STIRLING CYCLE, and the LINDE-HAMPSON LIQUEFACTION CYCLE (see [Figure E.60](#)).

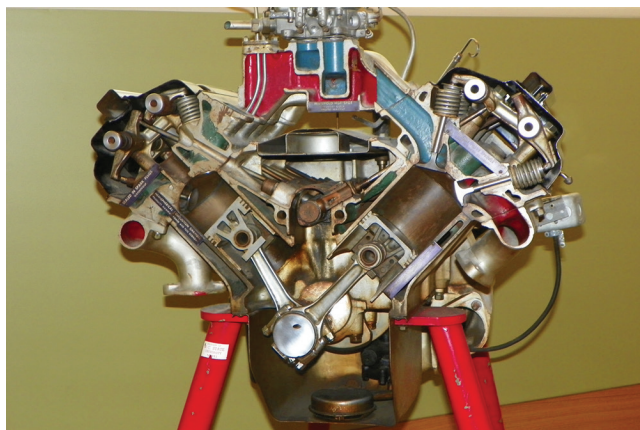


Figure E.60 Example of the engine displayed at North Carolina State University. A cross-sectional view of a mishmash of different mechanisms of action in the design of a combustion engine, presented here in a V-twin format.

Engineering

[general] A classification of science, mathematics, and technological applications related to the practical implementation of scientific concepts in order to design, construct, and validate devices and processes. Engineering also involves the integration of the economic impact (marketing) and practical application (ergonomics, social, and ease-of-use constraints) into the system development, quality control, and COMPLIANCE with standards for health and safety. The intended design applications are to forecast the behavior and operational performance under specific operating conditions with respect to its intended function. Software engineering is a generalized virtual application that integrates math, science, and technology in an algorithm that can simulate the process or function. Other applications of engineering are in the data acquisition and data processing aspects of technology, economics, biology, and THERMODYNAMICS and any aspect of integration and overlap between these functional segments. The first-known use of the term and concept of engineering has been documented in 1720. It is a cross-functional multidiscipline integrating FLUID DYNAMICS, MECHANICS, thermodynamics, material sciences, OPTICS, chemistry, biocompatibility, biology, design, draftsmanship, ACOUSTICS, ELECTRONICS, software code, geology, METEOROLOGY, astronomy, HYDRAULICS,

pneumatics, and nuclear, but not limited to the number of fields and including a range of other disciplines, such as textiles and agriculture as well as architecture (see Figure E.61).



Figure E.61 Examples of engineering.

Enthalpy (H)

[fluid dynamics, thermodynamics] The sum of all energy contributions in chemical reactions both required for the breaking of bonds and needed for forming new bonds. When a reaction is endothermic, the change in entropy is positive, whereas for an EXOTHERMIC REACTION, $\Delta H < 0$. In case the reaction is endothermic, the change in enthalpy is positive ($\Delta H > 0$). Enthalpy is also defined as the cumulative contributions of INTERNAL ENERGY (U) and work performed on the external environment (W), which is primarily confined to the volumetric change under constant pressure, written in incremental format as $H = U + W = U + PV$, with P and V being the pressure and volume of the system, respectively. The heat-transfer in a system is equal to the enthalpy change in the system: $\Delta H = \Delta Q$. This makes the heat of vaporization the difference between the enthalpy of the LIQUID phase and the VAPOR phase. In the case of constant pressure, the change in enthalpy is equal to the HEAT (Q) added to or removed from the system (see Figure E.62).

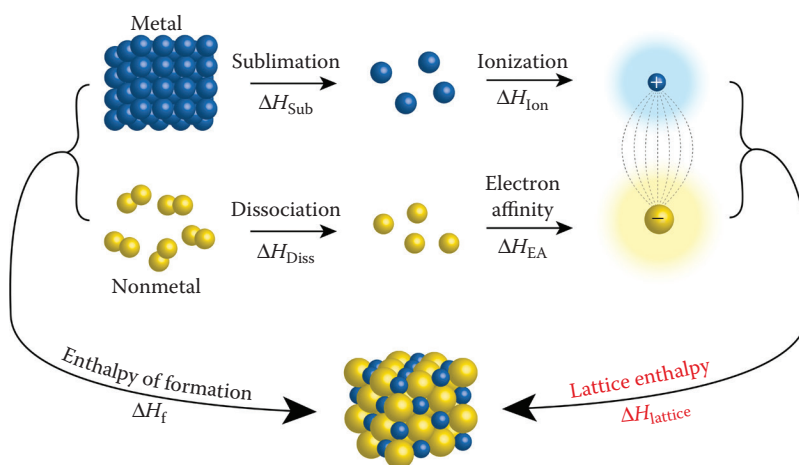


Figure E.62 Schematic representation of the lattice enthalpy of formation.

Entropy (S)

[computational, fluid dynamics, thermodynamics] Measure of order or disorder in a system. It was introduced by RUDOLF JULIUS EMANUEL CLAUSIUS (1822–1888) in 1865. The entropy of a system is the partial derivative change in free energy (F) with respect to changing temperature (T): $S = (\partial F / \partial T)_{N,V}$ under constant atomic content (N) and constant volume (V). Entropy is a measure of molecular randomness or disorder, defined by the total number of (energetic-) states in a system expressed by the Boltzmann equation using the thermodynamic PROBABILITY $\mathcal{P}$, written as $S = k \ln \mathcal{P}$, where k is the Boltzmann constant. Systems that are well ordered have a low entropy, primarily due to the low probability of the system being so well ordered. When HEAT (Q) is added under constant temperature (T), the system becomes more disordered due to kinetic interaction between molecules resulting in breaking of bonds (covalent or chemical) and will transition in a new state with higher entropy: $\Delta S = \Delta Q / T$. A clear example is melting ice where the amount by which entropy has increased is a direct function of the heat provided by external sources. Another way of expressing the entropy is with respect to internal temperature: $S(A) = \int_O^A dQ / T = \int_O^T (C_p(T) dT) / T$, yielding the difference in entropy between two energetic states of a system, where O is an arbitrarily chosen initial state, T the ABSOLUTE TEMPERATURE, dQ the HEAT TRANSFER into/out of the system and A the final state of the medium. For solids, the second part holds true with, $C_p(T)$ the heat capacity of the system at constant pressure. In a different form as an absolute value the entropy is also described as a function of the number of dynamic states of a system at a given thermodynamic state, also called the “probability of state,” π , defined as the Boltzmann relation, $S = k^{10} \log(\pi)$, with k the Boltzmann constant. This can be written for an IDEAL GAS as $S = C_v^{10} \log T + R^{10} \log V + a$, with V and a being the volume of the ideal gas and the ENTROPY CONSTANT OF THE GAS, respectively. The entropy change in an ideal gas that is exposed to a abrupt EXPANSION is $S_2 - S_1 = -(W_{rev} / T) = N \ln(V_2 / V_1)$, with W_{rev} being the reversible work while changing volume (V), while changing from state₁ to state₂, and N being the number of gas atoms/molecules. A special case can be seen for ^4He at the melting temperature of 1.4 K; the entropy of the LIQUID is almost identical to that of the VAPOR. Even more remarkable is the solid–liquid curve for another QUANTUM LIQUID: ^3He , which has a negative slope (virtually horizontal for ^4He and positive for all general materials) that can be explained by the fact that liquid ^3He acts as a FERMI GAS, which as its atomic momentum states, ordered in the FERMI SPHERE, whereas the solid is not as well defined energetically. The entropy constant of a monoatomic gas is, for instance, $a = R^{10} \log((2\pi MR^{3/2} \omega e^{5/2}) / (h^2 + A^4))$ (see Figure E.63).

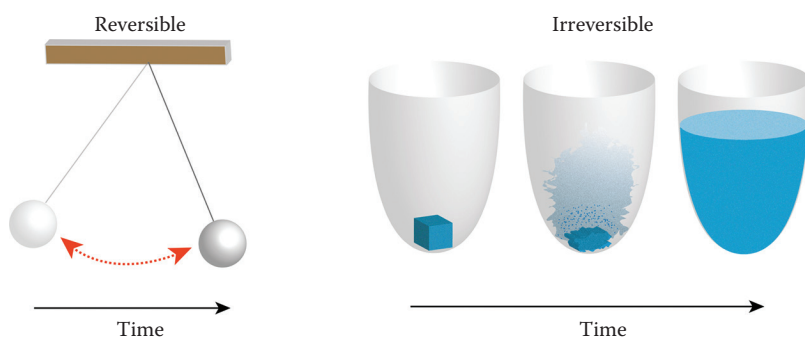


Figure E.63 Schematic representation of reaction entropy.

Eötvös number (Eo)

[fluid dynamics, mechanics] dimensionless number representing the quotient of the dependency between the gravitational force over the SURFACE TENSION. In the ratio, the following definitions apply: ρ the density of the droplet, ρ_f the density of the surrounding FLUID medium, L a characteristic length (size of droplet, confinement space, etc.), and σ_{surf} the surface tension: $Eo = (\rho - \rho_f)L^2 / \sigma_{surf}$. The Eötvös number describes

the momentum transfer in fluid atomization, as well as the classification of the calculations of the MOTION of BUBBLES and droplets. The Eötvös number has significant similarities to, and identical applications as the Bond number.

Epitaxial growth

[electronics, general, solid-state] In semiconductor construction (e.g., CHIP: silicon crystal designed to perform select electronic functions), layers are evaporated and deposited that will form a crystallographic structure that is consistent and a reproduction of the substrate layer (i.e., wafer or silicon structure). Note that crystallographic defects are similarly reproduced within each layer. Deposition can be facilitated by laser.

Epitaxial layer

[electronics, general, solid-state] In semiconductor manufacturing, the layer formed during deposition under EPITAXIAL GROWTH (see [Figure E.64](#)).

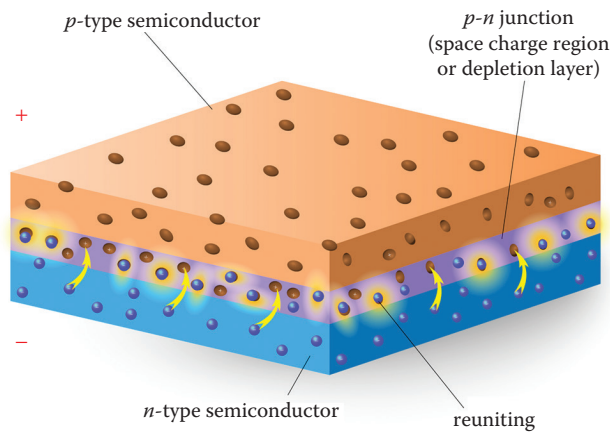


Figure E.64 The epitaxial layer in a *p*-*n* junction in semiconductor construction.

Epithermal neutron

[atomic, nuclear, thermodynamics] Energy configuration for NEUTRON that is released from a FISSION process and the neutron has slowed down but has not degraded to the THERMAL ENERGY level yet.

Eptesicus pulse

[acoustics, biomedical, theoretical] Pulse echo emitted by the family of *Eptesicus* bats (Big Brown BAT) during cruising flight (search mode), with four to five pulses being emitted per SECOND. During hunting mode, the number of acoustic pulses emitted by the *Eptesicus* bat increase to hundreds per second with as little as 5 ms interval between pulses, compared to 200 ms intervals during surveillance mode. This pattern

is very different from the MYOTIS PULSE. The *Eptesicus* bat is found in Europe, the mid-East/northern Arab nations, southern Russia, and China (see Figure E.65).

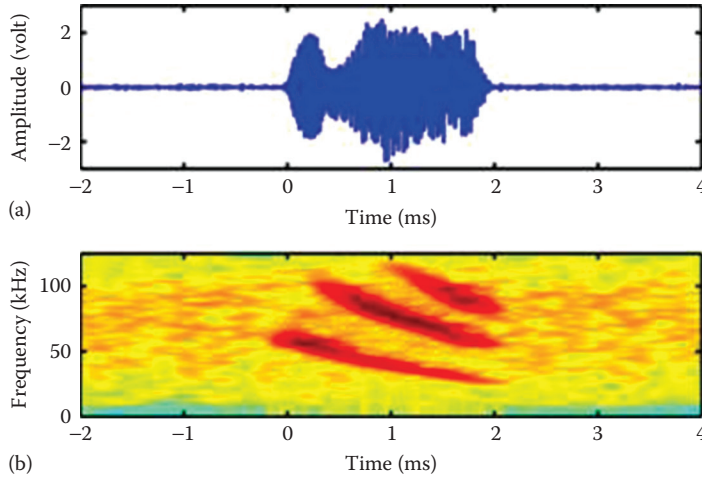


Figure E.65 (a,b) Spectral shape of the *Eptesicus* bat's echolocation pulse shape.

Equation of continuity

[general] See CONTINUITY and CONSERVATION LAWS.

Equation of Kármán–Nikuradse

[fluid dynamics] Flow description by THEODORE VON KÁRMÁN (1881–1963) combined with the work of Johann Nikuradse (1894–1979), a student of LUDWIG PRANDTL (1875–1953). Correction to the FRICTION in the viscous sublayer or WAKE region: $1/\sqrt{(C_f/2)} = 2.46 \ln \{C_f / (2Re_D \sqrt{(C_f/2)})\} + 0.29$, where $C_f = C/Re_D^{1/m}$ the coefficient of friction, Re_D the REYNOLDS NUMBER ($Re_D > 4000$), C a constant that is linked to the flow conditions, m a constant linked to the flow conditions, which represents the specific friction factor associated with the values tabulated for specific PIPE parameters, also known as “Prandtl’s universal law of friction” for smooth pipes. The equation incorporates specific aspects of TURBULENCE, and the respective influence on the viscous friction with respect to the WALL (see Figure E.66).



Figure E.66 The wake behind a ship created by the turbulence from the boat (object) moving through liquid, with relative velocity.

Equation of radiative transfer

[astronomy/astrophysics, biomedical, energy] An equation system describing the transport and interaction with media of ELECTROMAGNETIC RADIATION introduced by KARL SCHWARZSCHILD (1873–1916) for the theoretical description of electromagnetic wave propagation through galactic dust: $\vec{s} \cdot \nabla \mathbf{L}(\vec{r}, \vec{s}) = -(\mu_a + \mu_s) \mathbf{L}(\vec{r}, \vec{s}) + \mu_s \int_{4\pi} p(\vec{s}, \vec{s}') \mathbf{L}(\vec{r}, \vec{s}') d\omega'$, where $\mathbf{L}(\vec{r}, \vec{s}) = u(r_b) \Psi$ defines the spatial radiance of the electromagnetic RADIATION propagating through space in three dimensional format, with Ψ the radiation power received, transferred or emitted from a finite (small) sphere, $u(r_b)$ defines the spatial distribution of the source, ω is the SOLID ANGLE in space, $p(\vec{s}, \vec{s}')$ is the SCATTERING PHASE FUNCTION, μ_s and μ_a are the local SCATTERING and absorption coefficient of the medium, respectively, $\vec{r}$ is the direction and $\vec{s}$ is a segment of space, with $\vec{s} \cdot \vec{s}' = \cos \theta$ the scattering angular distribution (see $\mathbf{L}(\vec{r}, \vec{s}, t)$ and RADIANCE) (also see DIFFUSION, FLUENCE RATE, PHOTO-ACOUSTIC MICROSCOPY, RADIANCE, RADIANT ENERGY FLUENCE RATE, and TRANSPORT EQUATION) (see Figure E.67).

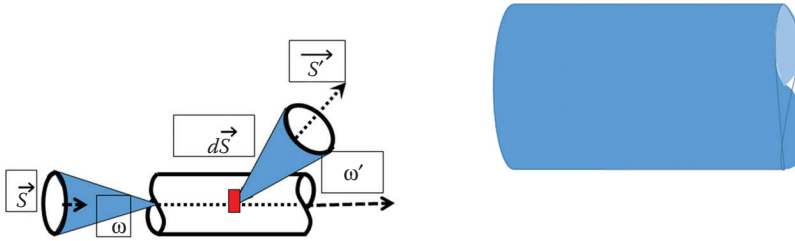


Figure E.67 Outline of geometric configuration for the redistribution process in the equation of radiative transfer.

Equation of state

[thermodynamics] The expression of the interrelation between PRESSURE (P), TEMPERATURE (T), and VOLUME (V) of a system indicating the interdependence as $f(T, P, V) = 0$, signifying that the remaining condition can be derived when two are known. The IDEAL GAS LAW is the most well-known equation of state for a single-phase system. Additionally, PHASE transitions can be incorporated as well. Specific applications of the equation of state are the Van der Waals equation, the Dieterici equation, the Beattie–Bridgeman equation and Benedict–Webb–Rubin equation. The Van der Waals equations reads as $(P + (a/V^2))(V - b) = RT$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant and a and b are constants that represent the specific properties of the substance. The expression for the compressibility of a substance also falls under the equation of state. The Dieterici equation is defined as $P = (RT/(V - b))e^{-(a/RTV)}$, which is derived from the Van der Waals equation and provides a correction for deviations with respect to the critical point. The Beattie–Bridgeman equation uses a slightly different approach as an extended iteration, expressed as $P = RT/V(1 - (c'/V^3)) [1 + (B_0/V)(1 - (b'/V))] - (A_0/V^2)(1 - (b'/V))$, where A_0 , B_0 , and a' , b' , and c' are constants that represent the specific properties of the substance. The most intricate is the Benedict–Webb–Rubin equation: $P = (RT/V) + (1/V^2)(B_0'RT - A_0' - (C_0'/T^2)) + (1/V^3)(b''RT - A_0') + (a''\alpha^*/V^6) + (1/V^3)(c''[1 + (\gamma^*/V^2)]/T^2)e^{-(\gamma^*/V^2)}$, with A_0' , B_0' , C_0' , and a'' , b'' , c'' , α^* , and γ^* constants that are tabulated, which represent the specific properties of the substance. Under certain conditions is has value to introduce the acentric factor: $\omega_s = -^{10} \log((P_{\text{sat}}(0.7T_c)/P_c)$, where P_c is the critical pressure, P_{sat} is the SATURATION (vapor-)pressure at a specific temperature, T_c is the temperature at the critical point, or critical

temperature. The equation of state is directly linked to the Gibbs energy, with the fall out to the PRINCIPLE OF CORRESPONDING STATES (see [Figure E.68](#)).

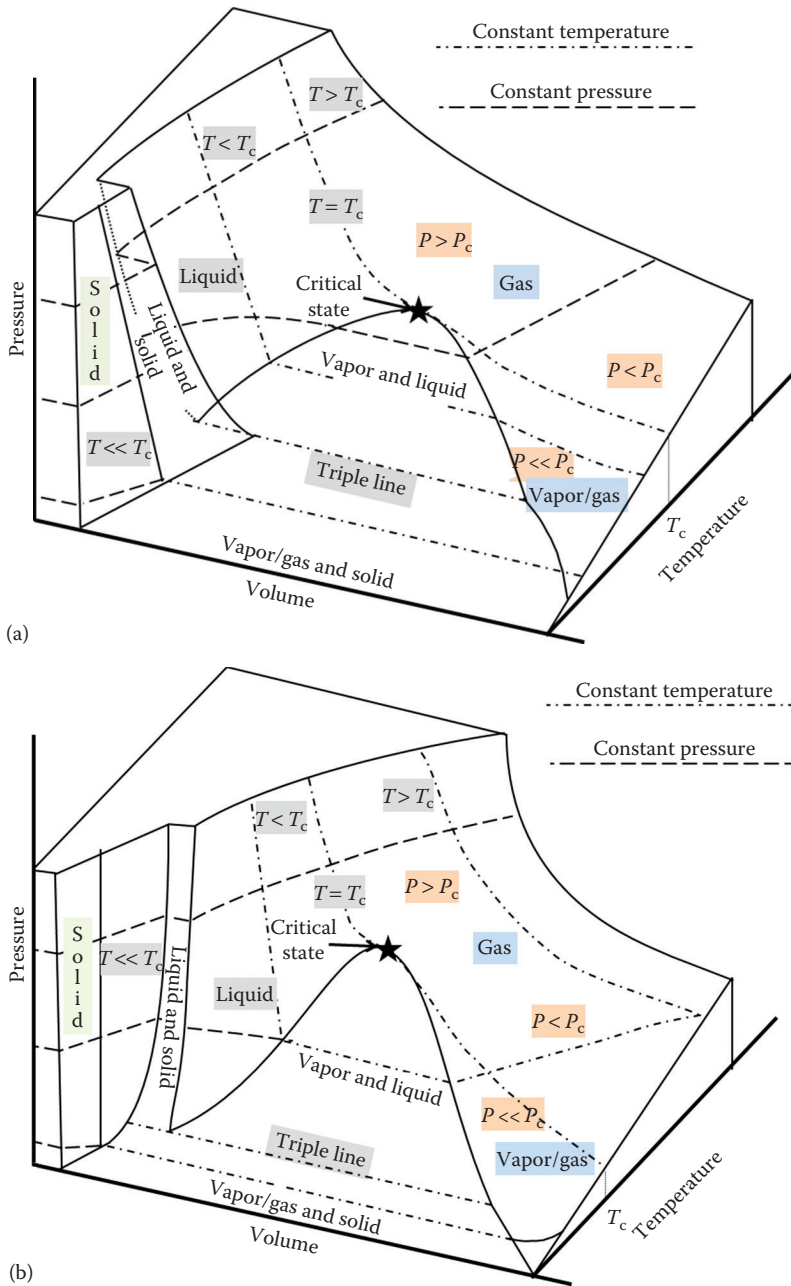


Figure E.68 Graphical representation of the conditions for the equation of state (a) H₂O. (b) Generalized medium that does not expand during the phase change from liquid to solid. (c) Phase diagram for generalized medium outlined by specific entropy and specific internal heat vs. specific volume. (Continued)

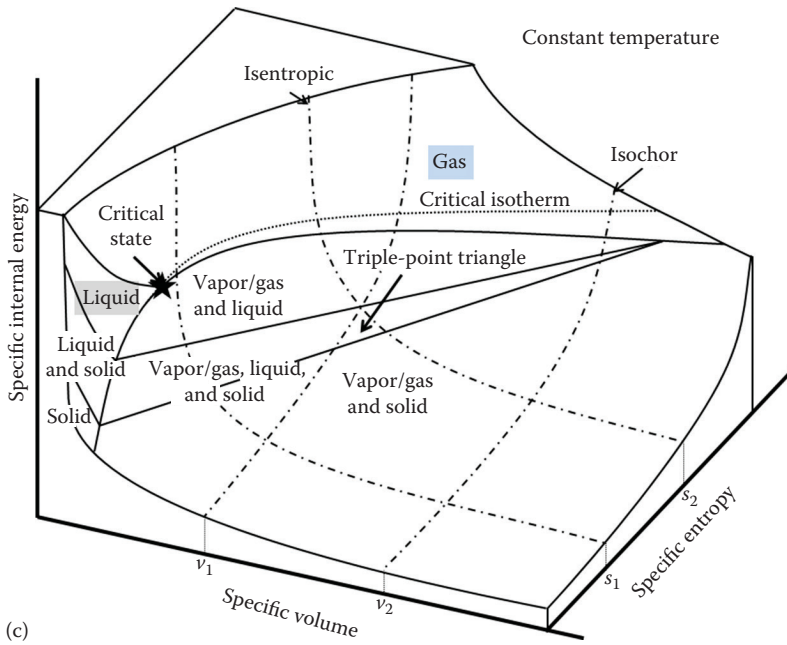


Figure E.68 (Continued) (a–c) Graphical representation of the conditions for the equation of state.

Equation of state of ideal gas

[thermodynamics] Combining the laws of BOYLE, GUY–LUSSAC, and AVOGADRO applied to each of the constituents i of the gas-mixture: $P_i V_i = (m/M_i)RT$, where P_i is the ABSOLUTE PRESSURE in the respective GAS, V_i the volume occupied by the gas m is the mass of the gas, M_i is MOLECULAR WEIGHT of the particular ELEMENT or molecule, T the ABSOLUTE TEMPERATURE in KELVIN, and $R = 8.3145 \text{ J/mol K}$ is the universal gas constant.

Equations of Blasius

[fluid dynamics] With respect to the boundary FLOW for a semi-infinite flat plate, the two-dimensional Navier–Stokes equations are used with respect to incompressible flow under the assumptions of negligible buoyancy and a constant free stream velocity. This reduces the problem statement to a two-dimensional situation (x, y) . Under these boundary conditions, $v_x = Ua(\eta_K)$, where $\eta_K = y/(\delta(x))$, $\delta(x) = (\eta_K x/U)$, v_x the flow velocity in the x -direction, U the limit of the velocity parallel to the plate at infinite DISTANCE ($v_x \xrightarrow{y \rightarrow \infty} U$), $\eta_K = \eta_D/\rho$ the KINEMATIC VISCOSITY, $\eta_D = (F/S_A)(b/U)$ the dynamic VISCOSITY (also found as μ), F the FRICTION force, S_A the surface area, b the thickness of the viscous layer (BOUNDARY LAYER), ρ the density, and $a(\eta) = df_{\text{flow}}/d\eta_K$ the acceleration, where $f_{\text{flow}} = \phi(x, y) + i\psi(x, y)$, $\phi(x, y)$ represents the VELOCITY POTENTIAL, and $\psi(x, y)$ represents the stream potential, or STREAM FUNCTION, describing streamlines that are by definition tangent to the velocity vector of the flow (Note: $v_x = \partial\psi/\partial y$; $v_y = \partial\psi/\partial x$), providing a flow function for a potentially irrotational and solenoidal vector field. The Blasius equation, named after PAUL RICHARD HEINRICH BLASIUS (1883–1970), scientist from Germany, now yields $(1/2)f_{\text{flow}}(d^2 f_{\text{flow}}/d\eta_K^2) + (d^3 f_{\text{flow}}/d\eta_K^3)$. The Blasius equation can generally not be solved analytically and requires a NUMERICAL approach, as outlined in the field of computational FLUID DYNAMICS.

Equations of Itaya

[fluid dynamics] The generalized Burger's equation for a compressible FLOW of a viscous FLUID. The equations are as follows in a one-dimensional system: $(\partial v(x, t))/\partial t = (\eta_{\text{visc}}/\rho(x, t))(\partial^2/\partial x^2)v(x, t) - v(x, t)(\partial v(x, t)/\partial x) - (K/\rho(x, t))(\partial \rho(x, t)/\partial x)$, respectively $(\partial \rho(x, t))/\partial t + (\partial/\partial t)\rho(x, t)v(x, t) = 0$,

where t represent time, K is a constant: $K\rho = P$, ρ the density, P the pressure, $v(x, t)$ the velocity, and η_{vis} the viscosity. Introduced by Nobutoshi Itaya (1933–) in 1970.

Equations of momentum

[fluid dynamics, mechanics] In general, the conservation of moment applies, next to the force integral over time to provide the momentum. However, FLOW momentum situations with particular applications in flow approximation specific to porous media can be resolved using FLUID DYNAMICS specific equations of momentum (see CAUCHY MOMENTUM EQUATION).

E

Equations of motion

[biomedical, quantum, thermodynamics] Set of differential equations (plural) that outline the conditions and operation of a system as a function of time specific to the particular state of the system. In classical MECHANICS, the equations of motion are described by NEWTON'S SECOND LAW. A system consisting of N particles can be analyzed for the individual particles as well as the system of particles on average. The equations arrange from displacement to energy. In displacement, the velocity is the first-order derivative with respect to location (r) as a function of time (t): $\vec{v} = d\vec{r}/dt$, generally defined as a vector with MAGNITUDE and direction with respect to the frame of reference. The acceleration is the derivative of velocity and the second order to time for location: $\vec{a} = d\vec{v}/dt = d^2\vec{r}/dt^2$, which may be repeated for individual components (ti) up to the total number N . Tying the force aspect in yields $\vec{F} = \sum_{i=1}^N m_i (d^2\vec{r}_i/dt^2)$. Under QUANTUM MECHANICS, the equation of MOTION is outlined by the SCHRÖDINGER EQUATION, as introduced by Erwin Schrödinger (1887–1961). Alternatively, under the Heisenberg approach, the state vectors are constant as a function of time, while the observables do change. The Heisenberg representation regards the changes in operators (H , HAMILTONIAN OPERATOR) or “observables” (A^*), as introduced by WERNER KARL HEISENBERG (1901–1976) in 1925. The Heisenberg PICTURE or Heisenberg representation with respect to the equations of motion is $(d/dt)A^*(t) = (i/\hbar)[H, A^*(t)] + (\partial A^*(t)/\partial t)$, where $[H, A^*(t)]$ is the commuter of the two operators: H and $A^*(t)$. For DIFFUSION as a function of concentration ($[C_i]$) of the respective constituents the equation of motion is $(1/\vec{r}^2)(d/d\vec{r})(\vec{r}^2(d[C_i]/d\vec{r})) = 0$. For FLOW, the equation of motion can be generalized as $(\partial\psi(\vec{r})/\partial t) + \nabla \cdot (\psi(\vec{r})\vec{U}) + \nabla \cdot \chi(\vec{r}) = \xi$, where $\vec{U}$ is the velocity field, ξ a state constant (characterizing external influences), which is zero under specific boundary conditions, $\chi(\vec{r})$ represents a diffusive transport term, and $\psi(\vec{r})$ represents the stream potential, or STREAM FUNCTION, describing streamlines that are by definition tangent to the velocity vector of the flow (Note: $v_x = \partial\psi/\partial y$ and $v_y = \partial\psi/\partial x$).

Equations of Nikuradse

[fluid dynamics] See EQUATION OF KÁRMÁN–NIKURADSE.

Equilibrium state

[thermodynamics] When a system is in equilibrium, the processes are generally in steady state with no net force acting on the system, confined under statics. There are many equilibrium conditions to be considered. Mechanical equilibrium applied to a system that is rotationally stable as well as translationally stable, meaning no changes in velocity or direction; this also applies to the geometry of an object and the way it may be placed on a three-dimensional surface. For instance, a ball placed on top of an incline will not be in equilibrium because there are no forces preventing the ball from rolling down the hill. A see-saw will be in equilibrium when none of the people seated use their muscles to change their position or push against the floor. Thermal equilibrium pertains to the fact to there is no heat exchange with the environment. A chemical equilibrium will result in a constant concentration for all the constituent, but resource and product. In a nuclear equilibrium the ATOM will not exchange particles (mass) or energy. A person sitting in a car that is not moving and does not have the ENGINE running while eating and drinking is not in equilibrium; however, the car and content (without the RADIO playing, no lights on and without the air-conditioning or heat running) are most likely in a situation that can be confined to an EQUILIBRIUM STATE. For a mechanical system,

the first condition of equilibrium is that the sum of all the forces is zero ($\sum \vec{F}_i = 0$), and the second condition of equilibrium means that the sum of the torques is zero ($\sum \vec{\tau}_i = 0$). The fact that there cannot be heat exchange is an additional requirement for equilibrium with the outside of the system $\oint \dot{Q} dA dt = 0$. Under the constraints of equilibrium, a LIQUID may not evaporate if the liquid is considered the confined medium; however, when the liquid is in a tank with room for AIR, the tank may be in equilibrium as a whole.

Equilibrium theory of tides

[fluid dynamics] The EARTH as a whole with the MOON and the SUN as its components are considered the system when the equilibrium conditions for the tides are evaluated. The tides on the Earth are affected by gravitational attraction from Earth as well as both the Sun and the Moon, captured by the net gravitational potential Φ_g , which is a three-dimensional matrix. Other forces result from centripetal forces as well as wind, next to perturbations of melting ice (which can be a slow process that in most cases can be discarded as a second- or third-order term) and precipitation (e.g., RAIN and SNOW) next to EVAPORATION may be a small influence that can be captured in a generalized term (Ω). Equilibrium “sea level” is defined by $\Phi_g + (1/2)\omega^2 \bar{r}^2 + \Omega = 0$, where ω is the Earth’s rotation and $\bar{r}$ the DISTANCE to the sea surface with respect to the center of the Earth. Technically, each parameter has both spatial and temporal perturbations (see Figure E.69).

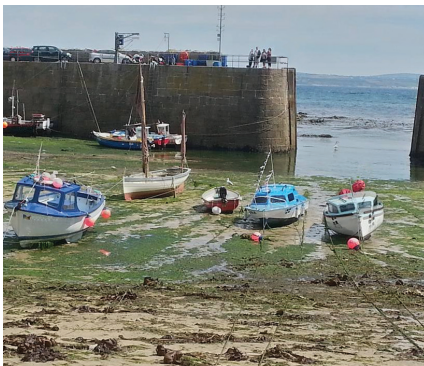
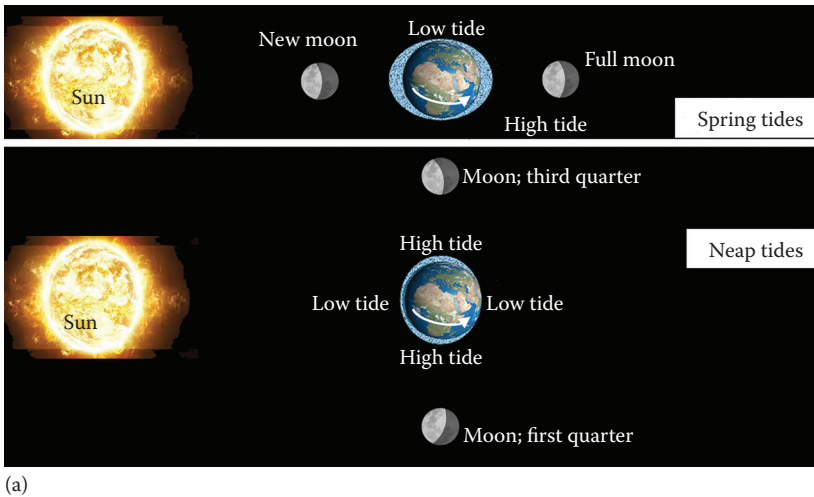


Figure E.69 (a) Outline of the influence of astrophysical objects (e.g., Sun and Moon, but potentially other celestial objects as well) on the tide level. (b) The tides may also affect commercial activity, a significant number of fish boats are grounded at low tide in this harbor. (c) Visual of how the tides affect the water migration process and create turbulent flow pattern. The turbulent flow is exemplified by the foam captured in the current, resulting from the capillary waves.

Equinox

[geophysics] A cross-sectional plane traversing the longitudinal outline of the equator where the average path of the SUN touches on its azimuth increases or decreases to the Tropic of Cancer in the northern hemisphere or the Tropic of Capricorn in the southern hemisphere. Because the EARTH is slanted at an ANGLE with the rotational plane, the NORTH Pole will be closer to the Sun on one half of its revolution around the Sun. The Sun will have its highest position (closest to the North Pole) when “above” the Tropic of Cancer. During the Earth’s elliptical path around the Sun, the cross-sectional plane outlined by the Earth will make the Sun pass North over the equator during the vernal EQUINOX. The vernal equinox defines the beginning of spring on the Gregorian calendar. The vernal equinox is around March 20 (give or take up to 2 days earlier or later, depending on calendar adjustments). When the Earth’s track places the Sun above the Tropic of Cancer, the calendar beginning of summer for the Northern hemisphere is initiated. Alternatively, the average position of the Sun’s geographical location crosses the equator in southern direction around September 22 (give or take up to 2 days either way, depending on calendar adjustments) indicates the beginning of autumn. Passing the equator this time named the autumnal equinox. After which the Sun proceeds onward for its average position before it reached the Tropic of Capricorn as the calendar onset for winter. *Note:* Seasonal changes geared to the Northern hemisphere (see Figure E.70).

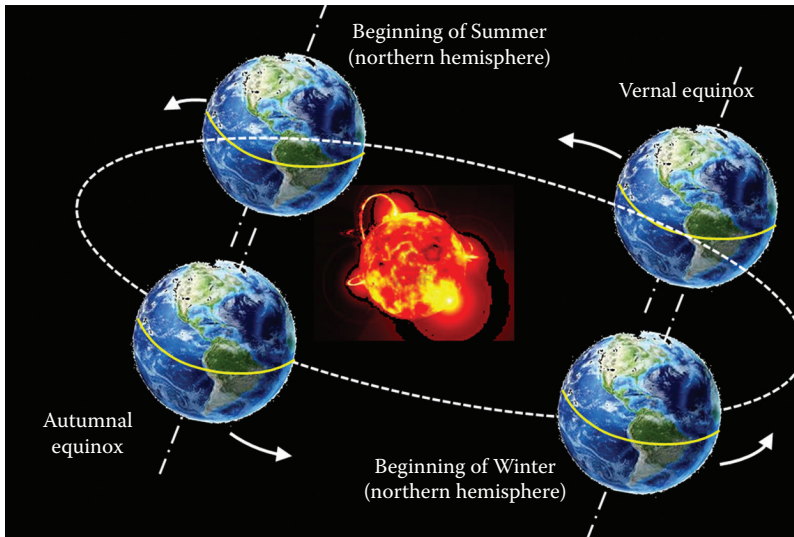


Figure E.70 Position of the Earth with respect to the Sun defining the respective equinox orientation.

Equipartition theorem

[atomic, computational, general, nuclear] Generalization of the temperature of a classical system to its energy content. All forms of energy are shared equally over the various DEGREES OF FREEDOM of the system. For a medium at temperature above ABSOLUTE ZERO, the distribution of vibrational to rotational to translational energy (contributing to the temperature) should be 1/3 to 1/3 to 1/3. The equipartition theorem predicts that for a monoatomic GAS the energy will be the average kinetic energy: $KE = (3/2)\epsilon_b T$, where $\epsilon_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann coefficient, T is the temperature (in Kelvin). For an electron gas interaction with phonons, the equipartition theorem provides the following $n(\epsilon_F) \hbar v_F q'^2 \phi_q'^2 = \epsilon_b T$, with ϵ_F the Fermi energy, $\hbar = h/2\pi$: where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck’s constant, v_F the Fermi velocity, q' the, ϕ_q' ; all within the BRILLOUIN ZONE. This may, for instance, apply to LATTICE structures thermal lattice vibrations.

Equipotential surfaces

[atomic, general, nuclear] The electrical POTENTIAL (V) resulting from an ELECTRIC FIELD (E) as a function of DISTANCE from one location with a fixed potential (r) is defined as $V = Er = (1/4\pi\epsilon_r\epsilon_0)(Q/r)$, connecting all locations with the same potential will yield the equipotential surface for the charge distribution Q .

Equipotential volume

[atomic, general, nuclear] The volume of a CONDUCTOR enclosed by the equipotential surface obtained by Gauss's law, with no internal electric field.

Equivalence principle

[general, relativistic] Equality of the inertial mass (m_i is the mass of a body that makes it resist MOTION, only when a force [F] is applied, yielding an acceleration [a]: $F = m_i a$) and gravitational mass (m_g); the mass that provides a body with weight due to interaction with other bodies [e.g., EARTH]), which is a central concept in the GENERAL THEORY OF RELATIVITY. The general theory of relativity proposes that GRAVITY is the cause of INERTIA.

Erg

[general] Unit of work done by a force of 1 dyne acting through a DISTANCE of 1 cm. The unit of energy that can exert a force of 1 dyne through a distance of 1 cm. CGS units: dyne-cm, or gm-cm²/s².

Ergodic hypothesis

[computational] In statistical PHYSICS, the ergodic theory describes the dynamic system with an invariant measure that exhibits the same behavior for the ensemble averaged as the same system averaged over time for all system states involved (*also see* MARKOV CHAIN).

Ether

[general, geophysics, optics] See AETHER.

Euclid (c. 325–270 BC)

[general] A mathematician from Greece. Euclid's work inspired the introduction of Euclidian space. Euclid is often referred to as the "father of geometry" (see [Figure E.71](#)).

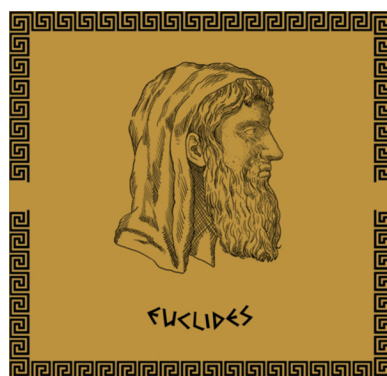


Figure E.71 Impression of what Euclid (c. 325–270 BC) may have looked like.

Euclidean geometry, axiom of

[computational] Postulation of equality documented approximately in 300 BC by EUCLID (c. 325–270 BC), stating that “parameters that are equal to the same phenomenon are inherently equal to one another.”

Euclidean space

[computational, general] A three-dimensional space describing rotational and translational vectors in Euclidean geometry (the geometry that has been the basis of “*modern geometry*”, omitting the “Euclidean” denomination part due to the fact that there have been no other comprehensive definitions of geometric space since EUCLID [c. 325–270 BC]). Euclidean space is based on the following six definitions and concepts: point, line, ANGLE (skew lines), parallel, orthogonal, and congruence. A point is undefined apart from the location of another point in reference to the first point (generally a point is set as the reference and is called the “origin”), two points connect to form a line with a length and a DISTANCE, two lines that are not coplanar and intersect are at an angle (skewed) which lies in a plane that conforms to both lines, lines that are coplanar and never intersect are parallel (only one parallel line can pass through a single point that is not on the first line), lines that are passing through one single point and have the same angle on either side are orthogonal to each other, figures that are made from three or more lines that form a closed shape are congruent when there are two distances between two extreme points on each diagram that are identical. The following postulates define the Euclidean space: (1) a unique line must be drawn between two points; (2) any line between two points can be extended to infinity; (3) a circle is defined by a central point and a radius; (4) all orthogonal angles are equal; and (5) a third line intersecting with two lines will form a connecting set of line (i.e., triangle) if the angle the third line makes with both lines is smaller on the same side than on the opposite side. The following axioms are associated with Euclidean geometry: (1) “parameters that are equal to the same phenomenon are inherently equal to one another”; (2) the sum of equals are equal to the sum of identical equal numbers of line definitions and equal angles; (3) the whole of a collection of parameters is greater than the individual parts. In support of Euclidean space, the practical use of the value of π may have been known for centuries prior, but ARCHIMEDES (287–212 BC) made his formal derivation and definition around 250 BC; one of the most appropriate approximations is $22/7$ (see Figure E.72).

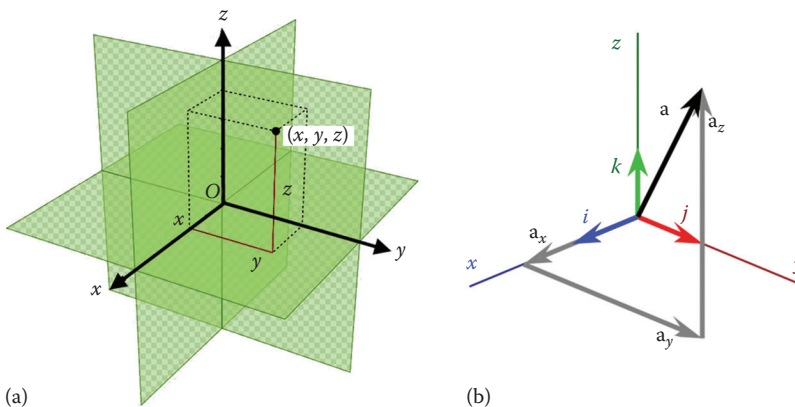


Figure E.72 Outline of (a) Euclidean space and (b) Euclidean vector.

Euler, Leonhard (1707–1783)

[acoustics, computational, fluid dynamics, general, mechanics, thermodynamics] A scientist and mathematician from Switzerland. Leonhard Euler’s work introduced the exponential dependency named after his last initial: “ $e = 2.718281828\dots$.” The number e plays an important role in numerous biological and natural phenomena specifically as exponent and NATURAL LOGARITHM (see Figure E.73).

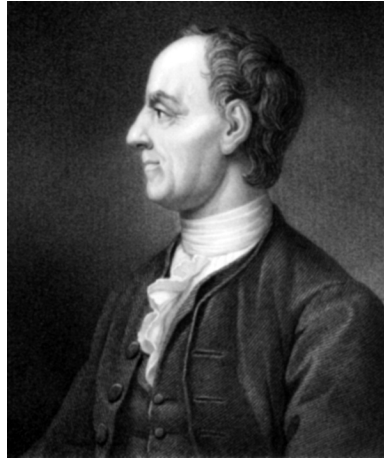


Figure E.73 Leonhard Euler (1707–1783). (Engraving by B Holl and painting by Jakob Emanuel Handmann.)

Euler angle

[astrophysics, energy, fluid dynamics] Set of three ANGLES in EUCLIDEAN SPACE that identify the orientation of a rigid body, introduced by LEONHARD EULER (1707–1783). The angles define the rotational matrices, rotating around the three respective axes: x , y , and z . The rotation matrices can be interpreted as follows. For a rotation of θ around the x -axis:

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta \\ 0 & \sin \theta & \cos \theta \end{bmatrix};$$

respectively a rotation ψ around the y -axis:

$$R_y(\psi) = \begin{bmatrix} \cos \psi & 0 & \sin \psi \\ 0 & 1 & 0 \\ -\sin \psi & 0 & \cos \psi \end{bmatrix};$$

and around the z -axis with EULER ANGLE ϕ :

$$R_z(\phi) = \begin{bmatrix} \cos \phi & -\sin \phi & 0 \\ \sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

Euler number (E_n)

[computational] In number theory, this represents a sequence of integers defined by a Taylor series EXPANSION as: $(\cos ht)^{-1} = (2/(e^t + e^{-t})) = \sum_{n=0}^{\infty} (E_n/n!) \times t^n$. In this description, the hyperbolic secant gives the secant numbers or zig numbers representing the number of odd alternating permutations.

Euler number ($Eu = (\Delta P/\rho v^2)$)

[fluid dynamics, mechanics] A representation of the ratio between pressure and inertial force. The pressure gradient $\Delta P = P_{\text{upstream}} - P_{\text{stream}}$ is the pressure drop over, for instance, a VALVE or other constriction, and the KINETIC ENERGY density (kinetic energy per unit volume) is expressed by the DENSITY (ρ) times

the characteristic FLOW VELOCITY (v) squared. Even though this resembles the CAVITATION number, the functionality is entirely different. The Euler number can be used to rank the frictional losses in the momentum of the flow, where $Eu = 1$ represents frictionless flow.

Euler relation

[thermodynamics] The energy content of a system with r constituents is defined as $U = TS - PV + \sum \mu_i n_i$, where U is the internal energy, T the temperature in kelvin, S the entropy, μ_i the chemical potential of constituent i and n_i the respective quantities; named in honor of LEONHARD EULER (1707–1783) (*also see* GIBBS ENERGY).

E

Euler's equation

[acoustics, computational] The primary definition of the Euler principle is in the complex notation of points in a two-dimensional space as $e^{i\kappa} = \cos \kappa + i \sin \kappa$. Additional application with respect to the equation of MOTION with respect to a body moving around its axes (e.g., TURBULENCE and governing INVISCID FLOW) is $\vec{N} = (\partial \vec{L} / \partial t) + \vec{\omega} \times \vec{L}$, where $\vec{L} = \vec{\omega} \left(\sum_i m_i |r_i|^2 \right) - \sum_i m_i r_i (r_i \cdot \vec{\omega})$ is the angular momentum, r_i is the DISTANCE and direction of the respective masses m_i to a point of reference, and $\vec{\omega}$ is the angular velocity. The Euler equations use the moment of INERTIA ($I = \sum_i m_i |r_i|^2$, with respective angular momentum: $\vec{L}_k = I_k \vec{\omega}_k$) to yield the Euler equations: $\vec{L}_k = I_k (\partial \vec{\omega}_k / \partial t) + (I_m - I_l) \vec{\omega}_l \vec{\omega}_m$ $\{k, l, m (1, 2, 3)\}$. It is named after LEONHARD EULER (1707–1783). The Euler equations are of particular importance in the analysis of inviscid flow by adding the equations for CONSERVATION OF MASS, conservation of momentum, and CONSERVATION OF ENERGY (E) without VISCOSITY and without HEAT TRANSFER, in corresponding to the Navier–Stokes equations. This corresponds to the following set of equations for FLOW with density ρ , pressure P , and velocity function $\vec{u} = (u, v, w)$ as: $(\partial \rho / \partial t) + \nabla \cdot (\rho \vec{u}) = 0$; $(\partial (\rho \vec{u}) / \partial t) + \nabla \cdot (\vec{u} \otimes \rho \vec{u}) + \nabla P = 0$; and $(\partial E' / \partial t) + \nabla \cdot (\vec{u} (E' + P)) = 0$, where $\otimes$ is the convolution or TENSOR product for the energy density $E' = \rho \hat{e} + (1/2) \rho (u^2 + v^2 + w^2)$ where $\hat{e}$ is the energy density.

Euler–Cromer method

[computational] A mathematical expression used to dissect the processes of a harmonic OSCILLATOR as a refinement to the original ideas of LEONHARD EULER (1707–1783) implemented by Tom Cromer (?–?) in the 1980s. The original Euler method introduces a set of incremental steps to solve the differential equations analytically based on the following process. The ANGULAR VELOCITY (ω) is defined as the first-order derivative with respect to TIME (t) for the changing ANGLE (θ): $\omega = d\theta / dt$, which in turn is converted in a set of series: $\omega_{n+1} = \omega_n - \theta_n \Delta t$, respectively: $\theta_{n+1} = \theta_n + \omega_n \Delta t$, $t_{n+1} = t_n + \Delta t$, with energy $E_{n+1} = (1/2) (\omega_{n+1}^2 + \theta_{n+1}^2) = E_n (1 + \Delta t^2)$, which is apparently ever increasing. The Cromer correction is as follows: $\theta_{n+1} = \theta_n + \omega_{n+1} \Delta t$, which yields for the energy: $E_{n+1} = E_n + (1/2) (\omega_n^2 - \theta_n^2) \Delta t^2 + O(\Delta t^3)$, providing a converging series instead (*also see* RUNGE–KUTTA METHOD).

Eutectic composition

[thermodynamics] System of two or more constituents that can all coexist with both the LIQUID and the solid phases at the same temperature (i.e., the eutectic temperature).

Ev

[electromagnetism, energy, general, thermodynamics] Electron-volt, the energy (also expressed in joule, unit J) of an electron under the influence of an electrical potential of 1 V: $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Evanescent wave

[acoustics, biomedical, general, imaging, mechanics, optics, quantum] WAVE phenomenon that is remaining within a close proximity to the interface between two media. Generally, the evanescent wave is formed when a wave enters into a BOUNDARY LAYER at grazing ANGLE and propagates reflecting of the boundary layer and the bulk medium with bulk REFLECTION coefficient at angles in excess of the CRITICAL ANGLE (i.e., TOTAL INTERNAL REFLECTION between the external medium 1 and the internal medium 2: $R_0 = n_1/n_2$). The bulk reflection for a (half-infinite) optical medium is defined by Kubelka–Munk RADIATIVE TRANSFER theory introduced by the Austrian physicist Paul Kubelka (1900–1953?) and the German (Prussia) scientist Franz Munk (1880–1951) in 1931. The bulk medium reflection is defined as $R_\infty = 1 + (K/S) - \sqrt{[(K/S) + 1]^2 - 1}$, where λ represents the wavelength of ELECTROMAGNETIC RADIATION, K the Kubelka–Munk absorption CROSS SECTION, and S the Kubelka–Munk scattering cross section. The Kubelka–Munk theory was developed for the quality assessment of painted surfaces. The Kubelka–Munk parameters relate to the universal optical absorption (μ_a) and scattering coefficient (μ_s) as follows: $K = 2\mu_a$, and the SCATTERING cross-sectional factor has a more intricate connection, involving the reduced scattering coefficient, which involves the scattering anisotropy factor (mean cosine of scattering angle: $g = \cos \theta$) as $\mu'_s = (1 - g)\mu_s$, which can be measured directly, providing $(4/3)S + (1/6)K = (1 - g)\mu_s$. For light, the media interface and the bulk tissue under grazing angle of incidence will form the equivalent of two opposing mirrors, trapping the light to travel along the surface with exponential DECAY in radiance with respect to depth (i.e., DISTANCE from the interface), not sinusoidal. In ACOUSTICS, the evanescent wave can be formed in several ways; for instance, in ATMOSPHERIC LAYERS, a thin layer of AIR can force itself between two layers of air that are stacked and have distinctly different densities (e.g., INVERSION layer). The air forced between the two stacked layers will form a flutter (similar to blowing air between your lips: “whistle”), creating a spatial frequency pattern of condensed air forming strips of clouds. Evanescent wave also apply to certain conditions in SCHRÖDINGER EQUATION. The evanescent profile can be used for selective ablation (removal of thin layers of media by performing a process similar to LITHOGRAPHY, ranging to molecular ablation) as well as diagnostics due to the specific characteristics associated with the evanescent propagation, and the inherent media parameters represented (*also see* LAMB WAVE) (see Figure E.74).



Figure E.74 Example of evanescent wave in the atmosphere. The pressure troughs create condensation, manifesting as rows of clouds.

Evans, Robley Dunglison (twentieth century)

[nuclear] A physicist from the United States who provided a detailed description of the construction of the atomic NUCLEUS.

Evaporation

[general] Conversion from LIQUID to gaseous state, called VAPOR, by administering heat. The heat requirement (Q) is set by the heat of vaporization: L_v and the total affect mass m as $Q = mL_v$.

Evaporation rate

[thermodynamics] The rate of conversion of LIQUID into VAPOR, measured in seconds ($t = 1s$). This mechanism will provide a mechanism of COOLING by using the HEAT OF VAPORIZATION (L_v) for the liquid to be extracted from the substance covered by liquid with MASS m , yielding a POWER (P) output of the body based on the HEAT EXCHANGE (Q) per SECOND: $P = Q/t = mL_v/1$. The rate of VAPORIZATION is given by $m_{\text{liquid}}/t = Q/L_v$. In human cooling, sweat serves as the mechanism of action, only when evaporated, not when dispelled as liquid as drops or wiped.

Ewald sphere

[solid-state] The spherical configuration with respect to electromagnetic or PARTICLE wave (*Note: DE BROGLIE WAVELENGTH*) interrogation of a LATTICE structure. The vector length resulting from crystalline INTERFERENCE with respect to the reciprocal lattice point outlines a spherical shape described by PAUL PETER EWALD (1888–1985), a physicist from Germany. The graphical representation by means of the Ewald sphere applies to electron diffraction, NEUTRON diffraction as well as X-RAY crystallography and is a variation of Bragg's law for lattice diffraction defined by drawing a sphere with radius reciprocal WAVELENGTH (λ): $R = 1/\lambda$, originating from the "real crystal," where the circumference intersects with the reciprocal lattice for the transmitted beam. The DISTANCE between the planes of the crystal is defined by the cord (d_{hkl}) for the location of the reciprocal lattice point on the sphere with respect to the direction of the interrogating beam as $1/d_{hkl}$ (see [Figures E.75](#) and [E.76](#)).

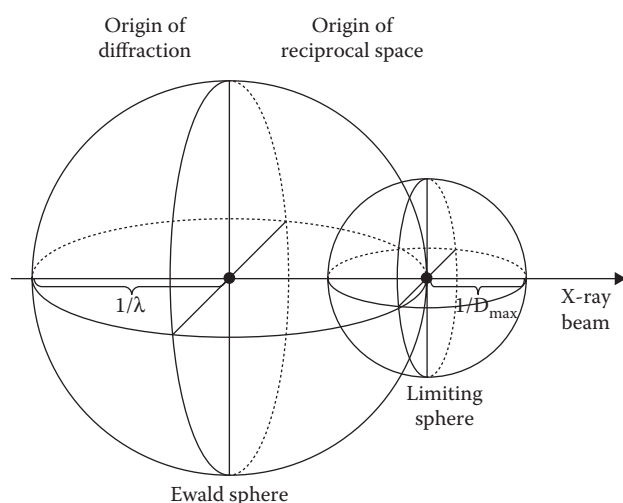


Figure E.75 Geometric outline of the Ewald sphere configuration. The Ewald sphere allows the visualization of a diffraction process; diffraction can only occur in the geometry where a reciprocal lattice point intersects the Ewald sphere.



Figure E.76 Paul Peter Ewald (1888–1985). (Courtesy of International Union of Crystallography, Chester; *Acta Cryst.*, A42, 1–5, 1986.)

Exchange interaction

[computational, electronics, quantum] QUANTUM mechanical symmetry relation linked to the intrinsic SPIN of electrons in their interaction with atoms, specifically discontinuities in the energy distribution resulting from LATTICE impurities. The exchange interaction J_{exch} is an indication of the symmetry between all atomic particles. At a specific temperature, the scattering CROSS SECTION for electrons suddenly has a discontinuity, with an increase defined by the KONDO TEMPERATURE: $T_K = \epsilon_F J_{\text{exch}} e^{-(1/n_s J_{\text{exch}})}$, with ϵ_F being the Fermi energy ($\sim$ kinetic energy of free electrons) and n_s the number of quantum states (also known as the “density of states”) (see KONDO EFFECT and THERMOCOUPLE EFFECT).

Excited states

[general, nuclear] See ENERGY LEVELS.

Exclusion principle

[atomic, general, nuclear] Exclusion of conditions with respect to state. For instance, fermions within the same system cannot occupy the same state with the same QUANTUM numbers. The states are conditionally defined by the four principle quantum numbers n (principal quantum numbers: 1, 2, 3, ...), ℓ (ORBITAL ANGULAR MOMENTUM QUANTUM NUMBERS: 0, 1, 2, 3, ..., $(n-1)$), m_ℓ (orbital magnetic quantum numbers: 0; ± 1 ; ± 2 ; ...; $\pm \ell$), and m_s (spin angular momentum QUANTUM NUMBER: $\pm(1/2)$). As the NUCLEUS is constructed with energy levels tightly stacked from the bottom up to the highest kinetic energy level, the FERMI LEVEL (Fermi energy), there are few opportunities for nuclei to change states in this configuration. Each NUCLEON may be represented by a WAVE function that has the DE BROGLIE WAVELENGTH ensuring a discrete filling with subsequent waveforms and SPIN configurations, excluding two nucleons to occupy the same conditions at any time because the energy content under those conditions would approach infinity. Only two neutrons and two protons can occupy the same energy level, as long as their respective spins are opposite (up vs. down); this applies to any and every energy level. Hence, the nuclear structure is very stable indeed. Specifically, nuclides (NEUTRON and protons) group in quantities referred to as the “magic numbers” are extremely stable (resembling the atomic NOBLE GAS electron structure) with $Z = 2; 8; 20; 28; 50; 82; 126$. The exclusion principle indicates that the NUCLEAR FORCE has SATURATION levels. (also see PAULI EXCLUSION PRINCIPLE.)

Exergonic

[chemical, thermodynamics] Spontaneous chemical reaction where the Gibbs free energy is negative ($G < 0$).

Exocytosis

[biomedical] The active process of cellular expulsion of both solid and LIQUID material. The CELL MEMBRANE forms an enclosure (vesicle) that engulfs the material of interest to be discarded and transports the filled “BUBBLE” out through the cell membrane.

E

Exoergic reaction

[chemical, thermodynamics] Chemical reaction that liberates energy.

Exosphere

[general, geophysics] The external layer of the Earth’s ATMOSPHERE, beyond the THERMOSPHERE, ranging from approximately 640 km out to 10,000 km. The major components are hydrogen and helium, escaping from the thermosphere, at very low densities (see Figure E.77).

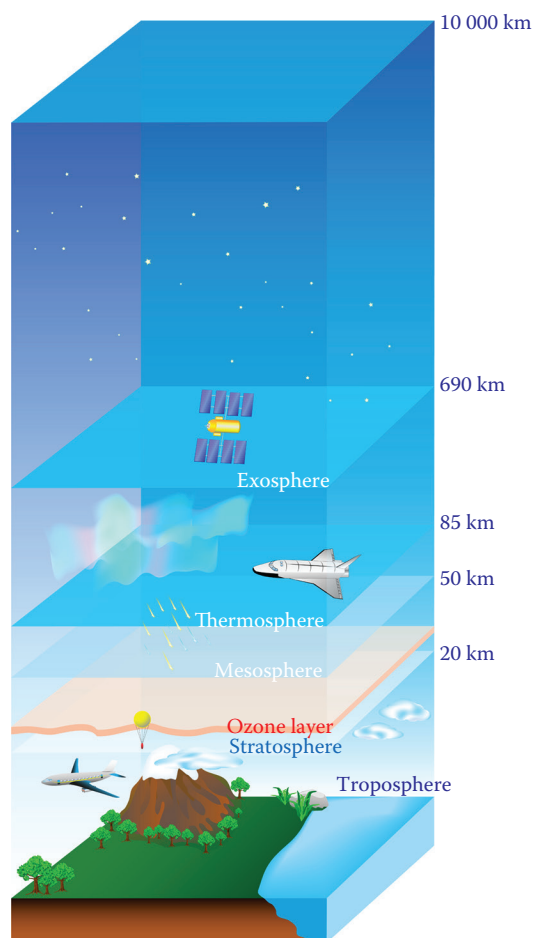


Figure E.77 The relative shell configuration for the Exosphere in the Earth’s atmospheric arrangement.

Exothermic reaction

[atomic, nuclear, thermodynamics] Process, chemical, or otherwise that produces heat. A prime example is OXIDATION and related general combustion. For an exothermic process of a system with r components, the enthalpy reaction $\Delta h(T)$ is negative: $\Delta h(T) = T\Delta S + V\Delta P + \mu_1\Delta n_1 + \mu_2\Delta n_2 + \dots + \mu_r\Delta n_r$, where T is the temperature, V is the volume, P is the pressure, S is the entropy, μ_i is the chemical potential of constituent i , and n_i is the respective quantities (see [Figure E.78](#)).



Figure E.78 Fire as an exothermic reaction, oxidation.

Expanding universe

[astronomy/astrophysics, nuclear] See **BIG BANG THEORY**.

Expansion

[general, fluid dynamics, mechanics] Most object and liquids expand under rising temperature, with the exclusion of, for instance, water, which has its highest density at 4 °C. Certain metals have different expansion profile with respect to temperature, encouraging the use of alloys that have an expansion coefficient that is not as large as the individual metals alone. This type of alloy is used in the construction of laser systems to ensure thermal stability. The expansion can be considered linear, two dimensional, or three dimensional (volumetric) depending on the specific application or interest, although the expansion in reality is always three dimensional. The linear expansion coefficient is the change in length (ℓ) with respect to the initial length as a function of temperature: $\alpha_{\text{ex}} = (\Delta\ell/\ell)\Delta T$; similarly, the volumetric expansion is $\gamma_{\text{ex}} = (\Delta V/V)\Delta T = 3\alpha_{\text{ex}}$. The following definitions apply: T is the temperature and V is the volume.

A mercury or ALCOHOL thermometer relies on expansion of the LIQUID in the GLASS tube for indication of the temperature, assuming that the radial expansion is negligible with respect to the longitudinal expansion of the glass tube in the process (see [Figure E.79](#)).



Figure E.79 Example of the impact of expansion with respect to a long single beam of railway iron track. The gap in between sequential segments prevents deformation during expansion.

Expansion wave

[fluid dynamics] *See* ACOUSTICS.

Expiratory reserve volume (ERV)

[biomedical, fluid dynamics] The quantity of air that can be ejected by maximum effort exhaling in succession to exhalation during gentle TIDAL BREATHING. Expiratory reserve volume and other tidal breathing parameters can be measured with a spirometer.

Exposition du système du monde (Exposition of the System of the World)

[general] A publication by the French mathematician PIERRE-SIMON DE LAPLACE (1749–1827) in 1798 describing the theoretical concept of a celestial object with a size 250 times that of the SUN with similar density as the EARTH would provide such a large gravitational attraction resulting in an escape velocity exceeding the speed of light in which case light would not be able to escape. Laplace thus provides the first hypothesis of the BLACK HOLE, without its observation or verification. The theoretical verification was provided in great detail under relativistic terms by KARL SCHWARZSCHILD (1873–1916) in 1916 and was experimentally verified in 1961 (almost 200 years later) by the binary system in the GALAXY Cygnus X-1.

Extramission

[biomedical, optics] Vision concept postulated by EUCLID (c. 325–270 BC), PTOLEMY (323–283), and PLATO (427–347 BC) in various versions, where the EYE is presumed to be capable of emitting rays that reflect from object and return to the eye for rendering the interpretation of the outside world. This concept could not explain the need for ambient light (no VISION in darkness). ARISTOTLE (384–322 BC) had already postulated that the eye captures light reflecting from light sources such as the SUN or a candle. However, the extramission theory was not abandoned until the scientific explanation by LEONARDO DA VINCI (1452–1519) of the workings of the eye in close resemblance to our current understanding. The experimental and theoretical OPTICS work by ALHAZEN (965–1040) formed the foundations for Da Vinci's revelations.

Eye

[biomedical, chemical, optics] In mammals, this refers to an anatomical feature constructed of an oblong shape constructed with a LENS (CRYSTALLINE LENS) at one side and a RETINA on the opposite side, separated by the VITREOUS HUMOR and an iris directly in front of the lens for the mechanical control of light intensity directed toward the retina. The lens is separated from the outside world by the AQUEOUS HUMOR covered by the cornea. Insects have a different construction of the mechanism of VISION called a “compound eye.” The various groups of animals defined by amphibians, birds, fish, insects, mammals, and reptiles; they all have specific design features that offer optimal adaptation to the conditions these groups live and seek for nourishment. The various components of the eye have the following respective optical characteristics, specifically for the INDEX OF REFRACTION (on average over the entire VISIBLE SPECTRUM of ELECTROMAGNETIC RADIATION): $n_{\text{cornea}} = 1.351$; $n_{\text{aqueous humor}} = 1.337$; for the lens the following index of REFRACTION applies to the optical axis $n_{\text{crystalline lens},0} = 1.437$; and the main body, the vitreous humor in general: $n_{\text{vitreous humor}} = 1.337$, while there is an optical “canal” with a different index of refraction with respect to the vitreous humor (lower) that confines the light, channeling it from the lens to the FOVEA (on the optical axis). Keep in mind that WATER has an index of refraction of $n_{\text{water}} = 1.333$ and for AIR $n_{\text{air}} = 1.000277$ at standard temperature (20°C) and pressure (1 atmosphere). The lens is shaped to correct for CHROMATIC ABERRATIONS in addition to a design of graded index of refraction (GRIN lens) as a function of radius that makes the lens more effective in focusing next to the accommodation process. The accommodation process applied force on the lens by means of the ciliary MUSCLE that stretches the lens and makes it thinner to focus on far off objects, whereas the lens is thick and rounded in the relaxed state for nearby IMAGE acquisition. The index of refraction of the lens of the eye as a whole in approximation has an index of refraction that is parabolic in nature as a function to the DISTANCE with the optical axis (r) as $n(r) = n_0(a + br - cr^2)$, where $n_{\text{crystalline lens},0} = 1.437$ and a , b , and c are positive constants. The eye as a whole is subject to age-related changes, one being that the central part of the lens starts hardening after the AGE of approximately 25. At this point, the lens will configure a portion of the gel-like structure into a NUCLEUS. With advances in age, this nucleus in the lens progressively becomes harder. The final outcome of the hardening process is cataract, with an inherent deterioration of transparency. Cataract will require replacing the lens with an artificial lens. Age-related changes to the composition and structure of the eye frequently result in corrections by means of spectacles (glasses) or refractive surgery (e.g., LASIK) (see Figure E.80).

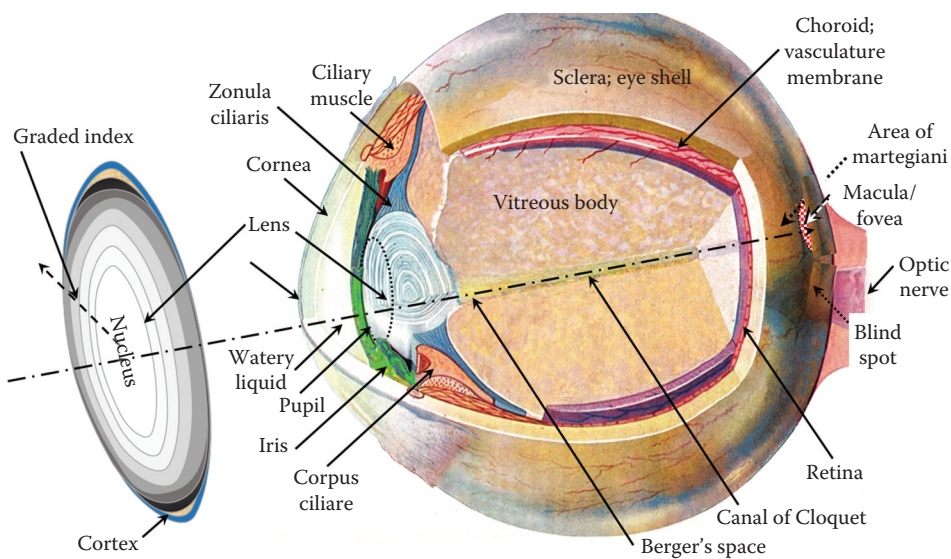


Figure E.80 Representation of the composition and components of the eye.

Eyeglasses

[biomedical, general] Optical prosthetic devices to correct for flaws and imperfections in VISION (see [Figure E.81](#)).



Figure E.81 Eyeglasses for corrective vision.

Eyring absolute rate equation

[chemical, condensed matter, energy] Equation describing the changes in energy configuration for a system based on the fact that the energy for each reaction is subject to QUANTUM THEORY because of the inherently discrete nature of the chemical reactions. The Gibbs energy change (ΔG) associated with the activation of the chemical reaction is defined as $\Delta G = RT \{ \ln(k_b/b) - \ln(k_r/T) \}$, $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant, using the Boltzmann constant $k_b = 1.3806488(13) \times 10^{-23} \text{ J/K}$, and PLANCK'S CONSTANT $h = 6.626070040(81) \times 10^{-34} \text{ m}^2\text{kg/s Js}$ yields $k_b/h = 2.08358 \times 10^{10} \text{ K}^{-1} \text{ s}^{-1}$, and k_r is the rate constant for the respective chemical reactions (function of the choice of concentration units, which directly correlates to the choice of thermodynamic GROUND STATE) and temperature (T) is expressed in Kelvin. The change in disorder associated with the increase in entropy ($\Delta S = S_{\text{final}} - S_{\text{initial}} > 0$) is inherently linked with the entropy of a system as defined by LUDWIG BOLTZMANN (1844–1906), as the natural log of all the possible configurations for a system ω_c is multiplied by the Boltzmann constant k_b : $S = k_b \ln \omega_c$, defining the maximum attainable entropy for a system. Under equilibrium, $\delta S = 0$. The change in internal energy (ΔU) as a result of external influences is concurrently defined by the change in enthalpy of the system: ($\Delta H = U + \Delta(PV)$), where the change in PRESSURE (P) multiplied by the VOLUME (V) represents the work performed by the system.

Applying the IDEAL GAS LAW to the constituents of the dilute system, this can be rewritten as $\Delta H = U + \Delta n RT$, where Δn represents the change in specific types of molecules because of the chemical reaction and R is the universal gas constant, temperature expressed in Kelvin. Under constant pressure, the work is volume labor only: $W = P\Delta V$. The enthalpy change for an EXOTHERMIC REACTION of a system is negative, that is, the chemical reaction produces heat, vice versa for an endothermic reaction. In this format, the Eyring absolute rate equation defines the rate constant as $k_r = (k_b T/h) \exp(-(\Delta G^\ddagger/RT))$. Using the standard enthalpy of activation $\Delta^\ddagger H^0$ and the standard entropy of activation ($\Delta^\ddagger S^0$), solving for the molecular quantity change Δn yields $k_r = (k_b T/h) \exp(\Delta^\ddagger S^0/R) \exp(-(\Delta^\ddagger H^0/RT))$, which provides the “linear” Eyring equation: $\ln(k_r/T) = -(\Delta^\ddagger H^0/RT)(1/T) + \ln(k_b/h) + (\Delta^\ddagger S^0/R)$. During this process, the HEAT TRANSFER of the system is equal to the change of enthalpy in the system: $\Delta H = \Delta Q$. The standard enthalpy of activation $\Delta^\ddagger H^0$ represents the enthalpy change derived from the thermodynamic form of the rate equation obtained from conventional transition state theory. In simplified form, the rate equation can be written as $k_r = A_1 \exp(-(E_1/RT))$, relying on the rate of change to take place at $k_b T/h$, with empirically derived coefficients $A_1 = (k_b T/h) \exp(\Delta^\ddagger S^0/R)$ and $E_1 = \Delta \Delta^\ddagger H^0$. These constants are per molecular context and will need to be determined experimentally. Combining the respective definitions of entropy and enthalpy

provides the change in Gibbs free energy of a system (G) as $G = \Delta U - T\Delta S - S\Delta T + \Delta nRT + nR\Delta T$. In a biological system, thermal process can provide denaturation of proteins (boil an egg, bake a steak, etc.). The denaturation process provides irreversible changes to the protein structure of a biological system, that is, coagulation. The coagulation process provides a change in internal energy associated with all the molecules that make up the system. The SECOND LAW OF THERMODYNAMICS states that for an irreversible process in an ISOLATED SYSTEM, the entropy always increases: $\Delta S_{\text{den}} = k_b \ln(\omega_{c,\text{denatured}}/\omega_{c,\text{native}})$. The denaturation process is given energetically by $\Delta G_{\text{den}} = \Delta H_{\text{den}} - T\Delta S_{\text{den}}$, which belongs to the respective chemical reaction: $a[A] + b[B] \rightleftharpoons c[C] + d[D]$, with $[C_i]$ representing the physical concentration of the reaction constituents, and a, b, c , and d are reaction coefficients. This provides $\Delta G_{\text{den}} = \Delta G_{\text{native}} + RT \ln\left(\frac{[C]^c [D]^d}{[A]^a [B]^b}\right)$. The activation energy for the denaturation process can be external from a fire, or laser in biology (clinical treatment) or chemical. The physical expression of the denaturation will be a biological (tissue) volume, which has been destroyed. The volume of denaturation can be derived by means of the DAMAGE INTEGRAL. The denaturation process is identified under MICROSCOPIC examination by histological markers of nuclear (i.e., CELL NUCLEUS) destruction (*also see* DAMAGE INTEGRAL) (see Figure E.82).

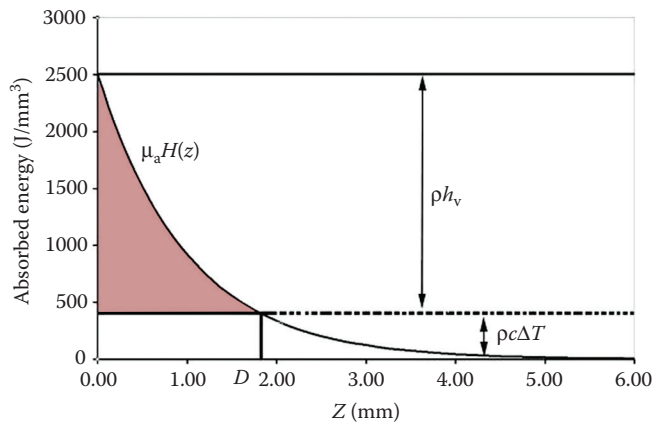


Figure E.82 Graphical outline of the Eyring absolute rate equation in a chemical process.



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F

$$F = m * a$$

[general] FORCE (F) is the product of the net acceleration ($a = \partial v / \partial t$, rate of change in velocity [v] with respect to time [t]) of an object with its mass m (see [Figure F.1](#)).

F



Figure F.1 Illustration of force, overcoming gravity by means of muscle action.

Fabry, Maurice Paul Auguste Charles (1867–1945)

[electronics, optics] Physicist from France, most known for the introduction of the INTERFERENCE principle in SPECTROSCOPY, primarily in collaboration with his colleague ALFRED PÉROT (also “Perot”) (1863–1925) (see [Figure F.2](#)).



Figure F.2 Maurice Paul Auguste Charles Fabry (1867–1945). (Courtesy of George Grantham Bain Collection, New York City; United States Library of Congress, Washington, DC.)

Fabry–Pérot interferometer

[atomic, optics] High-resolution INTERFEROMETER, designed for high-resolution spectral detection. The spectral RESOLUTION of the Fabry–Pérot interferometer is a direct function of the reflectiveness (R_{refl}) of the surfaces of the plate as well as the WAVELENGTH (λ) as: $\lambda/\Delta\lambda = m\pi\sqrt{R_{\text{refl}}/(1-R_{\text{refl}})}$, where m is the order of the INTERFERENCE. Interferometer named after the French inventors CHARLES FABRY (1867–1945) and ALFRED PÉROT (1863–1925), introduced in 1899. The Fabry–Pérot interferometer uses an optically transparent plate (or multiple plate configuration; i.e., aligned reflective surfaces), referred to as the Fabry–Pérot étalon, where “étalon” is the French word for “gauge of measuring,” “benchmark,” or “standard.” This interferometer is also used inside laser cavities for spectral filtration (see Figure F.3).

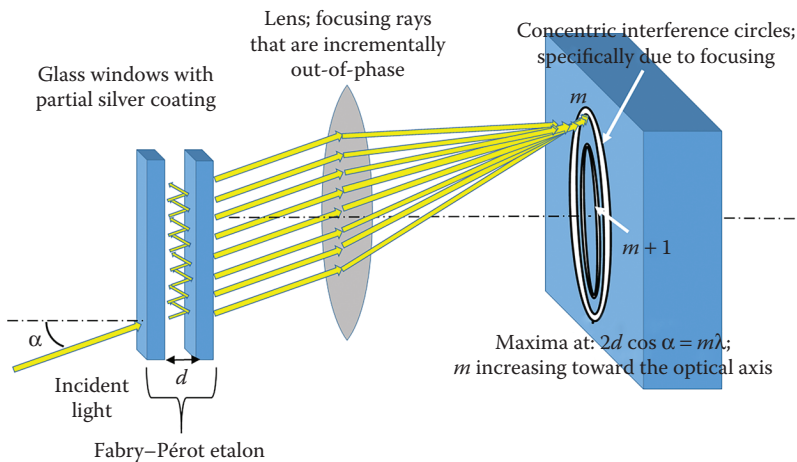


Figure F.3 Fabry–Pérot interferometer.

Fahraeus–Lindqvist effect (Fåhræus–Lindqvist effect)

[biomedical, fluid dynamics] The material effect where the VISCOSITY of a FLUID is a function of the dimensions of the FLOW system. This is applied in particular to colloid solutions, for example, BLOOD and slurry. Most well-known consequence is AGGREGATION of blood in small vessels, specifically the clumping of red blood CELL, both in ROULEAUX FORMATION under specific chemical conditions (hormonal and diseases related) as well as in CAPILLARY stacking. Since the RED blood cells have a diameter that is greater than the diameter of the capillaries, the red blood cells will stack as dishes on the counter of the dishwasher in a restaurant, primarily due to equilibrium force. RED blood cells will be transported with the central axis lining up perfectly with the axis of the vessel, scraping the WALL in circumference. Because of the FÅHRÆUS–LINDQVIST EFFECT the blood viscosity will drop sharply when the vessel diameter will decrease below a specific diameter ($D = 2R$), approximately 1 mm. In these arterioles, the flow RESISTANCE is close to the highest in the CIRCULATION; hence, the Fåhræus–Lindqvist effect provides a significant advantage for the blood PERFUSION. The apparent viscosity under the Fåhræus–Lindqvist effect can be expressed as follows: $\eta_{\text{app,FL}} = \eta_p \left[1 - (1 - (\delta/R))^4 (1 - (\eta_p/\eta_{bl})) \right]^{-1}$, with δ the cell-free PLASMA layer at the wall of the vessel, η_p the KINEMATIC VISCOSITY of the blood plasma, and η_{bl} the central viscosity of blood (non-Newtonian). The phenomenon is named after the scientists (pathologist and hematologist, respectively) ROBIN SANNO FÅHRÆUS (1888–1968) and JOHAN TORSTEN LINDQVIST (1906–2007), both from Sweden (see Figure F.4).

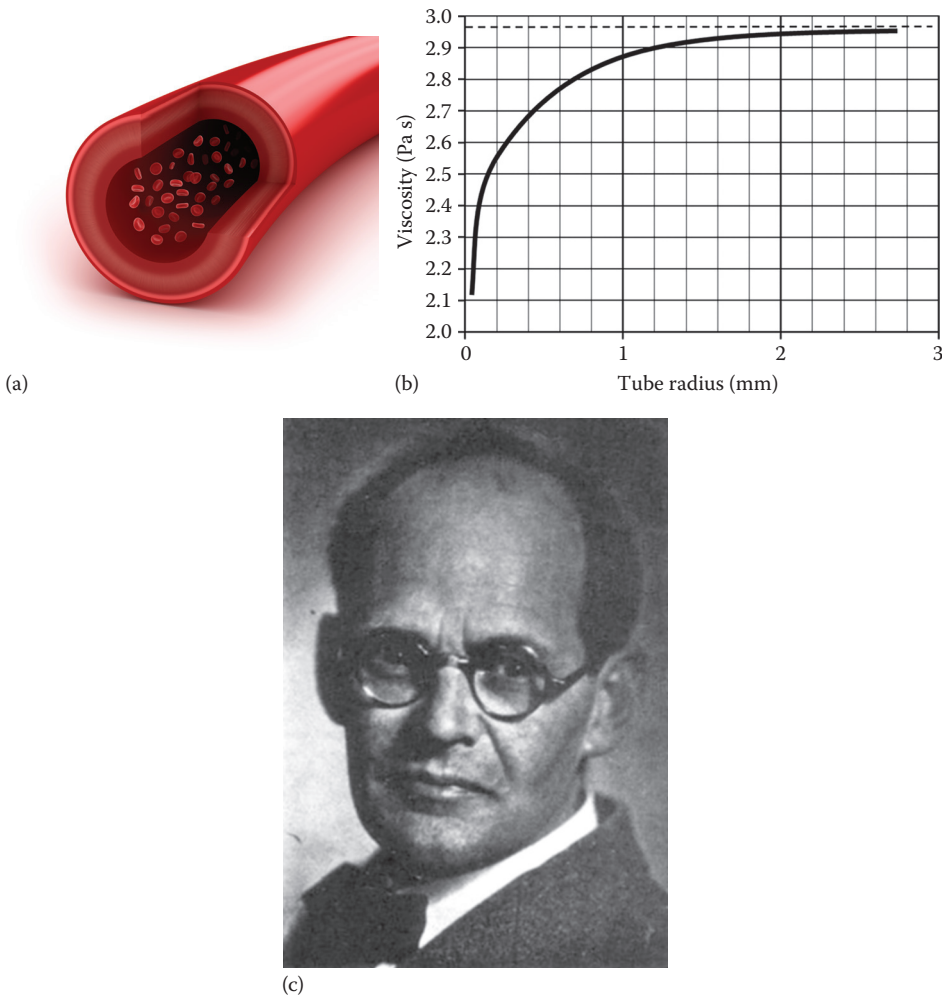


Figure F.4 (a) Cell-free layer at the outer radius of the blood vessel, (b) graphical representation of the Fåhræus-Lindqvist effect, and (c) Robin Fåhræus (1888–1968), photograph of Hans Christophersen. (Courtesy of Stiftelsen Upplands Museum, Uppsala, Sweden: Upplandsmuseet/Uppsalabild.)

Fahrenheit, Gabriel Daniel (1686–1736)

[general, thermodynamics] Physicist from the Prussian Empire (now his birthplace is in Poland), known for his introduction of the FAHRENHEIT TEMPERATURE SCALE. Gabriel Fahrenheit followed the inspiration left by his predecessor in the world of MEASUREMENT, CARLOS RENALDINI [RINALDINI] (1615–1698) who performed his temperature measurements almost 50 years prior. Another contemporary metrologist was ANDERS CELSIUS (1701–1744), whose temperature scale is used prevalently in the world apart from the United States. In the United Kingdom, the Fahrenheit scale has officially been discontinued since 1962, but common use persisted until the mid-1980s, with colloquial use of Fahrenheit still reported in current day newspapers and

thermometers often still provide a dual scale. Gabriel Fahrenheit was also a glassblower, this skill provided him with the tools to increase the accuracy of the temperature measuring devices (see [Figure F.5](#)).

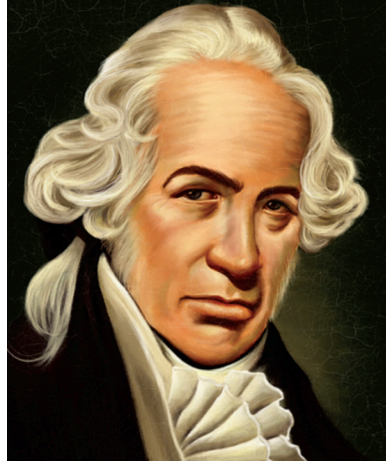


Figure F.5 Gabriel Daniel Fahrenheit (1686–1736). (Courtesy of Ogarnij Ogarna.)

Fahrenheit temperature scale

[general, thermodynamics] Temperature scale devised in 1724 by GABRIEL DANIEL FAHRENHEIT (1686–1736) using the FREEZING point of a mixture of SALT and water to provide the zero point calibration and the body temperature of his wife as 96°. The scale was later adjusted to the HUMAN BODY temperature at 98°. The conversion between the CELSIUS SCALE (°C) and the Fahrenheit scale (°F) is accepted globally, the latter being primarily used in the United States, as $^{\circ}\text{C} = (y^{\circ}\text{F} - 32)(5/9)$ (see [Figure F.6](#)).



Figure F.6 Fahrenheit scale.

Fanno flow

[fluid dynamics] FLOW system that is adiabatic and does not perform work, however, is subjected to WALL FRICTION. The flow takes place under steady-state conditions with constant cross-sectional area. Since no work is performed, the reference height (h_0) remains constant, as well as the MASS FLUX (ρv , for FLUID flow

with density ρ under flow velocity v), hence, $h_0 = h + ((\rho v)^2 / 2\rho) = \text{Const}$. A “Fanno line” in the entropy versus height diagram connects locations with the same h_0 and ρv (“momentum density”). Fanno flow can be considered under two conditions: subsonic flow and SUPERSONIC FLOW. Supersonic flow will result in a SHOCK WAVE.

Farad (F)

[general] “Système International” (SI) unit for the MAGNITUDE of capacitance. The unit is derived from MICHAEL FARADAY (1791–1867), in honor of his contributions to electrical theory.

Faraday, Michael (1791–1867)

[atomic, electronics, general] Physicist and chemist from England. In 1831 Faraday published the time varying MAGNETIC FIELD effects, where a moving magnetic bar (MAGNET) induces current, known as the FARADAY LAW. In addition, Faraday introduced several other concepts in ELECTRICITY and MAGNETISM such as the unit of charge: 1 Faraday = 96,485.3415 Coulomb. In the early 1820s, both Michael Faraday in England and JOSEPH HENRY (1797–1878) in the United States described the intercorrelation between electric fields and magnetic fields, which were used by JAMES CLERK MAXWELL (1831–1879) to develop the electro-magnetic wave theory and combining the four equations of Henry, Faraday, and JOHANN CARL FRIEDRICH GAUSS (1777–1855). The MAXWELL EQUATIONS outlined the fact that all ELECTROMAGNETIC RADIATION travels with the speed of light. In 1824, Faraday almost accidentally invented the rubber balloon as a result of GAS LAW experimentations (see Figure F.7).



Figure F.7 Michael Faraday (1791–1867). (Courtesy of J. Cochran.)

Faraday (F)

[nuclear] Unit of collective charge associated with one MOLE of electrons (each with charge e), named after MICHAEL FARADAY (1791–1867), $F = N_a e$, where the Avogadro number $N_a = 6.02214 \times 10^{23}$ molecules/mole.

Faraday, first law of

[atomic, general, nuclear, quantum, thermodynamics] During ELECTROLYSIS in a LIQUID ionic solution, the quantity of material transported is directly proportional to the applied current and the time exposure. The transported amount is also proportional to the amount of GAS released from the SOLUTION under applied current over the working time. Named after MICHAEL FARADAY (1791–1867), a chemist and physicist from Great Britain.

Faraday, second law of

[atomic, general, nuclear, quantum, thermodynamics] The ratio of the ELECTROCHEMICAL EQUIVALENT of two constituents is directly proportional to the ratio of the atomic weights of the components divided by their respective valences. For instance the valance of silver ($A = 108$) is unity and the valance of zinc ($A = 65$) is two, yielding for the electrochemical equivalent for zinc the derived SOLUTION from what is known for Silver by means of the mass ratio silver to zinc participating in the ELECTROLYSIS reaction as $(108/1) : (65/2)$. The QUANTUM explanation states that a material of VALENCE 2 can use halve the quantity to transport the equivalent amount of charge with respect to a material with valence 1. Named after the English chemist and physicist MICHAEL FARADAY (1791–1867), from England.

Faraday cage

[general] Conductive shell that has a closely knit wire DISTANCE, or solid CONDUCTOR plating, respectively, which will effectively provide the ideal conditions for the absence of an electric field inside the enclosure. Because of GAUSS'S LAW there can be no electric field line inside the confines of a conductive enclosure (including inside a solid). This is solely due to the fact that all charges will be spread out over the outermost surface, making the integration of the enclosed field lines over any surface that is smaller than the outer surface of the conductor that has no encapsulated charges. Additionally, in case of LIGHTNING strike, the surface of the conductor quickly spreads the charges over the surface leaving no net gradient of charges on the surface (see Figure F.8).



Figure F.8 Faraday cage, person wearing a conductive wire mesh that dissipates electrical discharge arcs.

Faraday constant

[atomic] Constant linking the electrical work (W_e ; in contrast to mechanical work, $W_m = P\Delta V + V\Delta P$, with P the internal pressure and V the volume of the system) to an applied electrical potential (ΔV_e is the maximum difference in the electrical potential resulting from the transferred charges) as, $W_e = -nF_a\Delta V_e$, with n is the number of charges transferred in the process, and $F_a = 96,485 \text{ C/mol}$ the Faraday constant.

Faraday dark space

[atomic, nuclear] In the process of the formation of the CATHODE ray in the Crookes rarefied GAS tube (after the English physicist SIR WILLIAM CROOKES [1832–1919]), an arc is formed at the location of the cathode (NEGATIVE CHARGE applied), while immediately in front of the cathode there is no LUMINESCENCE (absence of arc), referred to as the Faraday dark space, also named the Crookes dark space. Supposedly, the phenomenon was described first by MICHAEL FARADAY (1791–1867), and confirmed or documented by Sir William Crookes in 1870. The absence of discharge is due to the repulsion of charges by the cathode, removing the PLASMA charges away from the cathode charge concentration. Crookes also refined the observation by describing the total disappearance of the dark space when the GLASS tube was totally evacuated, after migrating first toward the ANODE. Once the glass tube is totally under VACUUM conditions, the glass itself on the anode side will begin to glow.

Faraday law

[atomic, electronics, general] Law of electromotive induction describing the electromotive induced voltage ($\mathcal{E}_{\text{emf}}$) in a circuit by a changing MAGNETIC FIELD through an open surface (S) defined as $\mathcal{E}_{\text{emf}} = -(d/dt)(N\phi_m) = -N(d/dt)(\phi_m) = -N(d/dt)(\int_S \vec{B} \cdot \vec{n} da)$, indicating the rate of change (dt) of the MAGNETIC FLUX (ϕ_m) from a magnetic field ($\vec{B}$) incident perpendicular ($\vec{n}$) to the surface S of the loop bounded by an electrical circuit, where N denotes the number of loops of the circuit. Named after the physicist MICHAEL FARADAY (1791–1867), from England (see [Figure F.9](#)).

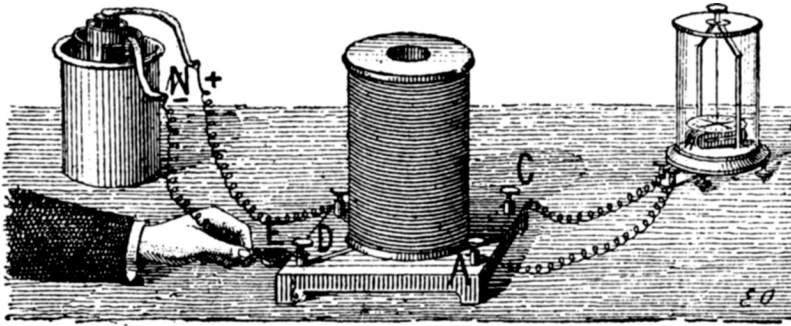


Figure F.9 The device used by Michael Faraday to conceive the Faraday's laws of induction.

Faraday's induction law

[general] See FARADAY LAW.

Far-field diffraction

[general] See DIFFRACTION, FAR-FIELD.

Farsightedness

[biomedical, general, optics] Conditions known for humans that are not able to accommodate the LENS (the lens will not “bulge” out to its full relaxed state or small radius of curvature) of the EYE in order to provide a clear focus of an object at close proximity. Under these conditions the IMAGE of an object at close proximity will be formed behind the RETINA of the eye. The “unwillingness” of the lens to form a fully

relaxed small radius of curvature is due to the loss of COMPLIANCE of the lens, primarily as aspect of loss of collagen with increasing AGE. Additionally, shortening of the eye ball itself can be a cause for this defect as well. This condition can be corrected by placing a POSITIVE LENS in front of the lens of the eye, or by artificially modifying the focal length of the eye by refractive surgery (e.g., LASIK). It is also known as hyperopia (in contrast to “presbyopia,” near-sightedness) (see [Figure F.10](#)).

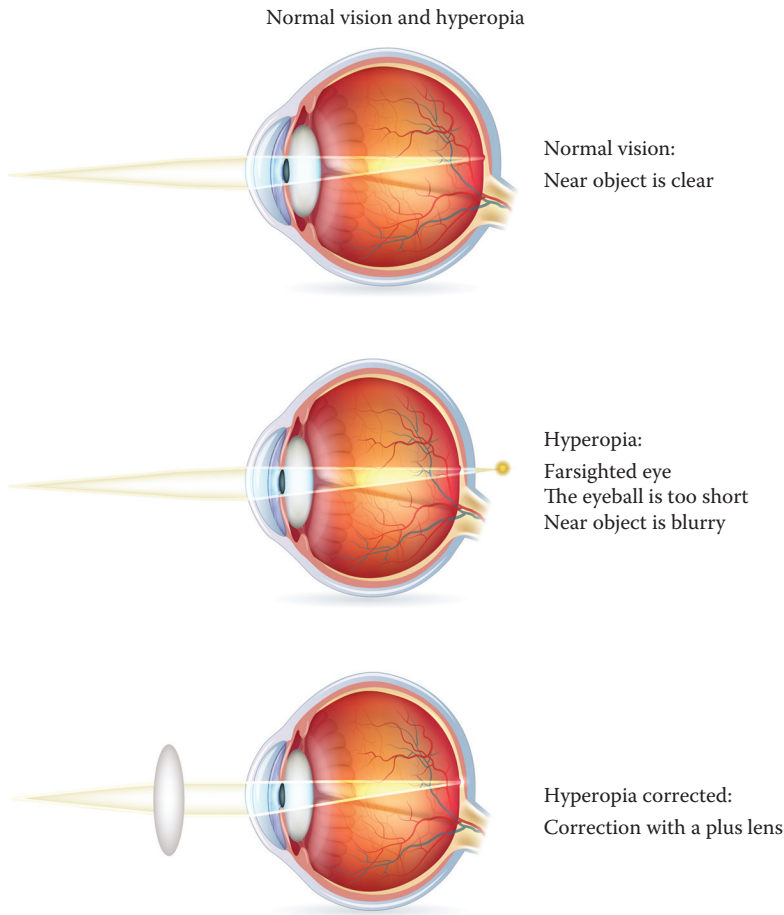


Figure F.10 How the deviation of the lens in the eye that produces hyperopia can be corrected.

Fast Fourier transform (FFT)

[computational] SEPARATION OF VARIABLES with respect to a frequency broadband SIGNAL in the respective base and harmonic waves, based on an algorithm and methodology introduced by the French mathematician BARON JEAN BAPTISTE JOSEPH FOURIER (1768–1830). FFT is an accelerated signal processing algorithm based on the discrete Fourier transform techniques, with the best acceptable resolution and amount of detail with respect to the processing time, based on several assumptions of regularity, reducing the number of computations required for signal processing of N data points from $2N^2$ to $2N \log_2 N$ computations. The FFT concept itself dates back to JOHANN CARL FRIEDRICH GAUSS (1777–1855) in 1805, and discussed in greater detail with elaborated principles by the mathematicians from the United States, SIR JAMES WILLIAM

COOLEY (1926–) and JOHN WILDER TUKEY (1915–2000) in 1965, and implemented in refined format in 1999 by the Australian mathematician and physicist Ronald Newbold Bracewell (1921–2007) based on the work he started in 1983. The Fourier transform principles use the conversion of time to frequency and vice versa as the basis. Both the Nyquist or Shannon theorem prescribe that a periodic signal must be minimally sampled at twice the fastest frequency phenomenon of the signal or IMAGE (spatial frequency). One specific example is the deconvolution of the heart DEPOLARIZATION signal: the ELECTROCARDIOGRAM (ECG), on its base signal in the range of 0.75 Hz (approximate average value at rest) to 3 Hz (running), with up to the first eight harmonics to be able to fully reconstruct the depolarization pattern. The MAGNITUDE of the harmonics can provide a quick analysis of potential clinical problems that require further attention, which will also require careful and meticulous analysis of the transient ECG pattern, specifically with isolation of ectopic BEATS (i.e., single beats that have a very different period from the “standard” HEART rate). It is also known as FFT (*also see* FOURIER TRANSFORM) (see [Figure F.11](#)).

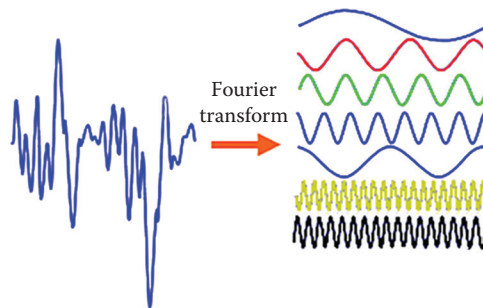


Figure F.11 Outline of the separate frequencies compiling the convoluted signal on the left under Fourier transform.

Fatigue

[general, mechanics] Failure mode of object subjected to cyclic stress (see [Figure F.12](#)).



Figure F.12 Failure mode of object that has been bent back and forth several times.

Fault line

[general, geophysics] Identified geologic feature that extends over a DISTANCE and is associated with the relative movement of landmasses with respect to each other, specifically under an EARTHQUAKE. Fault lines are defined based on their respective azimuthal orientation as well as the dip of the fault, outlining the

surface demarcation of a landmass fault. Several different types of faults can be identified. There is a strike-slip fault, which performs a lateral MOTION of the hanging WALL with respect to the footwall and have virtually no vertical displacement. Dip-slip faults slide over each other at a shear ANGLE with respect to the horizontal plane, acting as a ramp, making the hanging wall move at an incline angle with respect to the footwall. A specific configuration of the dip-slip fault is the THRUST fault, with a ramp angle of less than 45°, known as the most vigorous earthquake forming mechanisms (large Richter scale classification earthquakes). Another format is provided by the oblique-slip fault mechanism, also positioning the hang wall at an angle of incline with respect to the footwall and moving in both lateral and supine motion. Other fault formats are listric, ring, and synthetic/antithetic faults. Listric faults are identified by a curved fault separation between the hanging and the footwall. Ring faults are not specifically associated with tectonic plate, but more so with volcanic craters and meteoric impact sites. Fault lines can on a larger scale be correlated to the TECTONIC PLATES of the EARTH'S CRUST. The attributes of tectonic interactions are described by the following eight characteristics: (1) LATITUDE, (2) longitude and (3) depth (providing the epicenter); (4) origin time (providing the focus combined with the epicenter information); (5) MAGNITUDE OR ENERGY; (6) strike or azimuth; (7) dip of the relative movement; and (8) plunge (vector motion). Examples of specific fault lines are located all over the world. The San Andreas Fault, identified in California in 1895, extends over approximately 1300 km forming the fissure boundary between the North American tectonic plate and the Pacific plate; identified as strike-slip fault. The daily ACTIVITY of the San Andreas Fault is taken as part of everyday life in San Francisco, not discrediting the large number of more powerful earthquakes, including the one in 1906 with an estimated magnitude of 7.8 on the Richter scale. The Richter scale was introduced in 1935, developed under collaborative effort between physicist CHARLES FRANCIS RICHTER (1900–1985) from the United States and seismologist BENO GUTENBERG (1889–1960), originally from Germany, both working in the California Institute of Technology. The Richter scale uses the LOGARITHM of the AMPLITUDE of the SEISMIC recordings using a calibrated SEISMOMETER (mechanical vibrations) corrected for distance to the source, using three-point averaging between several stations. The Garlock Fault in California, extends over 250 km, is a left-lateral strike-slip fault located on the northeast–southwest of the NORTH margins of the Mojave Desert of Southern California. The Garlock Fault is under continuous motion, moving at 2–11 mm/year with additional 7 mm slip, but is not a majorly active earthquake fault. Another large fault line is near Charleston, South Carolina. Other fault lines in the United States are in Hawaii and Alaska. The South American Pichilemu and Liquiñe-Ofqui Fault fault lines are posing a significant threat to structural integrity and human lives. In China, the Longmenshan Fault (a thrust fault) extends over a length of 250 km and resulted in a 7.9 magnitude earthquake in 2008. Additionally, the Longmenshan Fault raises Tibet up by 4 mm/year. In Turkey, there is North Anatolian Fault (right-lateral strike-slip fault), which passes south of Istanbul and runs along the northern sea shore of the country. The North Anatolian Fault has endured many greater than 6.8 magnitude earthquakes (12 in the past 80 years). In Australia, the Moyston and Selwyn Faults have shown the capability of producing earthquakes with magnitudes between 7.0 and 7.5 on the Richter scale. Close to 100 different faults can be distinguished over the world. Apart from the Richter scale, the prior classification of earthquakes was made on the Mercalli scale (1931), based on a mixture of emotional impact and mechanical destructive impact. The energy in a tectonic shift (earthquake) ranges from approximately 10^8 – 10^{15} J. Activity in the region of fault lines can be recognized by animals prior to any mechanical activity is registered by the seismometric instrumentation. Specific characteristics associated with fault activity can be smells, tastes (water flavor changes due to MIXING of underground wells), and sounds. Additionally, during the movement, apart from the mechanical tremors there have been observations of light activity. Light activity observed has been glow in the sky, aurora's, next to "MICROSCOPIC" cavitation arcs at the soil level as well as frictional IONIZATION. The atmospheric generation of light can be the results of density changes in ATMOSPHERIC LAYERS next to the rapid changes in local MAGNETIC FIELD density. The study of faults is SEISMOLOGY (see [Figure F.13](#)).

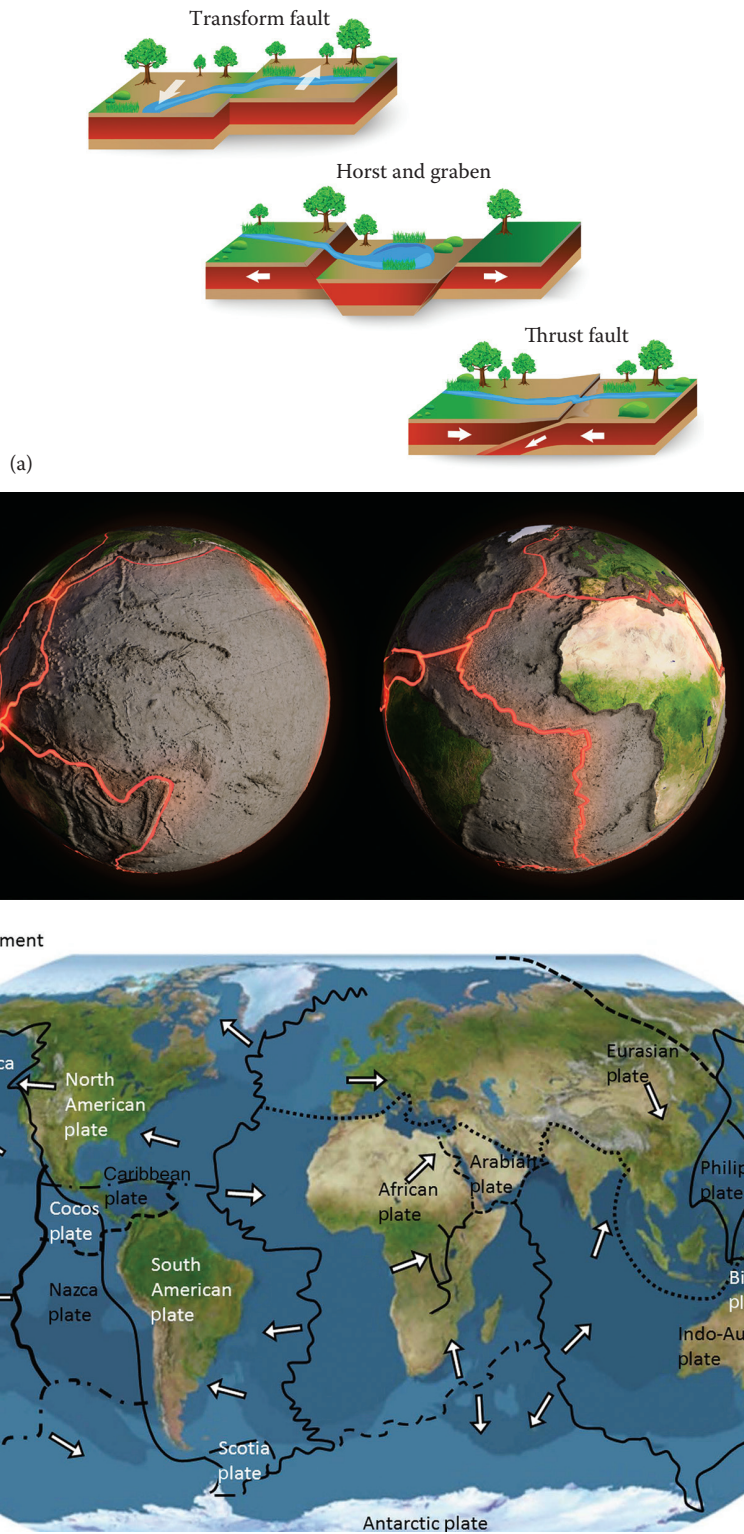


Figure F.13 (a) Types of fault lines and (b) the outline of the fault lines for the tectonic plates of the world. (c) Fault lines on a geographic map. (Courtesy of Maps of World.)

FDA

[biomedical] United States (US) Food and Drug Administration. Regulatory institution on governmental basis designed to oversee and control the safety and efficacy of medical devices and devices with medical and consumer aspects of medical intention. It is also called as USFDA.

Fermat, Pierre de (1601–1665)

[computational, general, optics] Lawyer and mathematician from France. Pierre de Fermat is best known for his treatise on OPTICS, the FERMAT PRINCIPLE is based on the geometric analysis of the rays of optics. Pierre de Fermat also worked closely with another contemporary French mathematician BLAISE PASCAL (1623–1662). The work of both Pascal and Fermat formed the mathematical foundation for the theory of PROBABILITY (see [Figure F.14](#)).



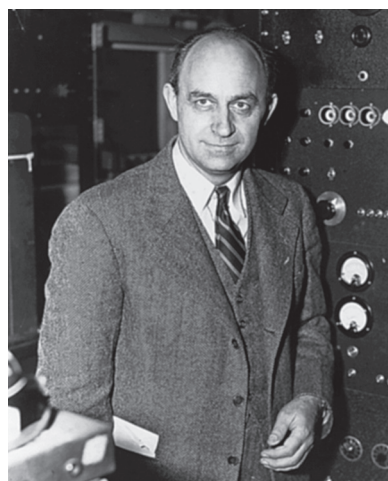
Figure F.14 Pierre de Fermat (1601–1665).

Fermat principle

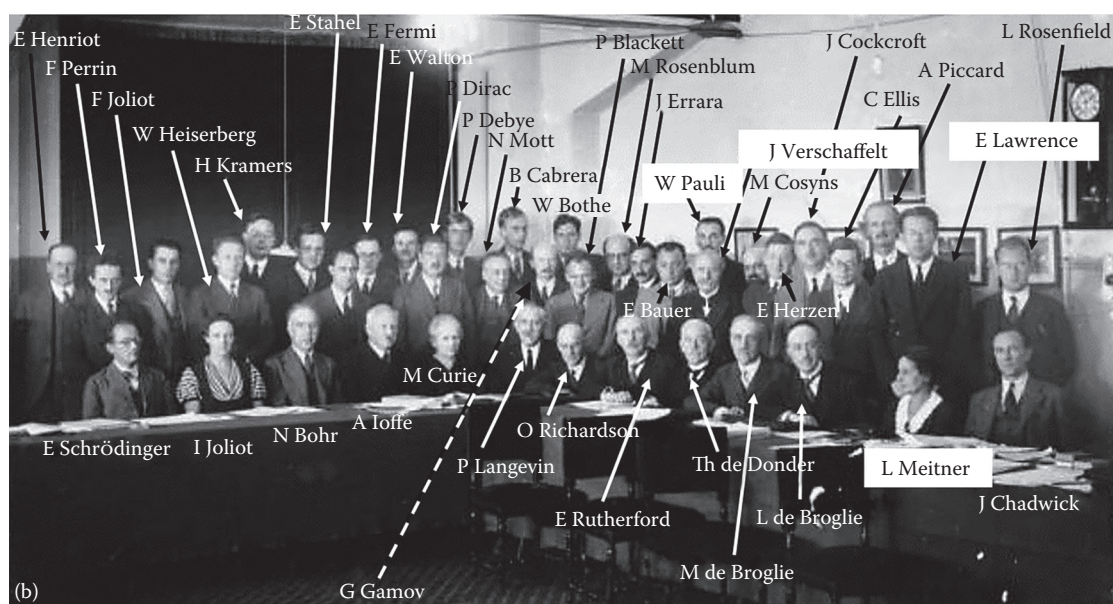
[optics] PHYSICS principle closely related to the action principle in classical mechanics. Analogously related to other physics principles, it describes all the appropriate PHYSICS LAWS pertaining to the GEOMETRICAL OPTICS principles to take place under the constraints of minimal time, derived by the French mathematician PIERRE DE FERMAT (1601–1665). In OPTICS it defines the path traversed by a beam of light between two points to proceed in the least amount of time. Applied to the WAVE theory of light, this also entails that small deviations in the path of light will not result in first-order deviations from the transit time. The extremes in optical path length are either minimal or maximal, as a function of the applied and persistent. One particular extreme providing a maximal path length will be realized under gravitational lensing. This ties into Snell's REFRACTION law from WILLEBRORD SNEL (SNELLIUS) VAN ROYEN (1580–1626) as well as the diffraction statement by AUGUSTIN-JEAN FRESNEL (1788–1827), more than century later. The Fermat principle is clearly visible under conditions of a heated asphalt or desert sand surface in the DISTANCE, producing a “mirage” also known as “Fata Morgana.” Under specific thermal conditions, a density gradient provides an optical path that may carry an IMAGE for tens of kilometers, beyond the edge of the horizon, or reflect an object in distorted view.

Fermi, Enrico (1901–1954)

[atomic, nuclear, solid-state] Italian physicist. He made major theoretical contributions to the description of the atomic model. His work was based on his use of neutrons in the creation of isotopes. The theoretical modeling included the introduction of SPIN orbit restrictions: PAULI EXCLUSION PRINCIPLE, and ENERGY quantization. He also played a key role in the development of the ATOMIC BOMB (see [Figure F.15](#)).



(a)



(b)

Figure F.15 (a) Picture of Enrico Fermi (1901–1954). (Courtesy of National Archives.) (b) Enrico Fermi attending the 1933 Solvay conference in Brussels, Belgium.

Fermi (unit of length)

[general] Equivalent to a femtometer ($1 \text{ fm} = 10^{-15} \text{ m}$) in honor of the Italian scientist ENRICO FERMI (1901–1954) as a characteristic length on nuclear basis, with respect to his introduction of the “NEUTRINO” as a definition for a nuclear PARTICLE in 1930, meaning “little neutral one.” Later the neutrino came to be named electron antineutrino, due to the fact that it was emitted from the NUCLEUS under CONSERVATION OF ENERGY along with an electron, based on the experimental observations of WOLFGANG PAULI (1900–1958).

Fermi decay

[nuclear] The process of nuclide beta DECAY is the most common in RADIOACTIVE DECAY, primarily due to the fact that a large portion of nuclides does not reside in the “valley of stability.” The beta decay process can be identified by the ORBITAL ANGULAR MOMENTUM that is disposed of as electron and NEUTRINO (i.e., electron

antineutrino) are emitted, next to the intrinsic change in PARITY as well as the respective alignment of the electron neutrino spins. When the ELECTRON SPIN is aligned with that of the electron antineutrino, the process is described by the GAMOW–TELLER DECAY, whereas when they are antiparallel the process is described by Fermi decay (as described in preliminary fashion by ENRICO FERMI [1901–1954] in 1934). The Fermi decay is the most common decay process, where the ALLOWED TRANSITION is confined to a transfer of zero (0) orbital angular momentum ($S_\beta = 0$, S_β spin of beta decay). Under these conditions, the decay constant is roughly proportional to the decay ENERGY to the fifth power. The QUANTUM mechanical equivalent decay process defined by Enrico Fermi uses similar concepts used in the electromagnetic decay process under classical MECHANICS, adapted to an “electron neutrino field.” The decay constant is defined based on a perturbation potential (ΔV) and the number of nuclide states (N_n) per unit energy (E), expressed as $dN_n/dE = (p^2(dp/dE)/2\pi^2\hbar)\ell^3$ (momentum $p = (\hbar\pi/\ell)n$; POTENTIAL WELL with dimension ℓ with energy $E = (\pi^2\hbar^2/2m_e\ell^2)(n_x^2 + n_y^2 + n_z^2)$, n an integer constant; $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck’s constant), which yields for the DECAY CONSTANT (τ_F) as a function of the eigenfunctions to the SCHRÖDINGER EQUATION (ψ_i ; complex conjugate ψ_i^* , ψ_i the excited NUCLEUS; ψ_f the final nucleus, after decay): $\tau_F = (2\pi/\hbar) \left| \int_{\text{Nuclides Volume}} \psi_i^*(\text{system}) \Delta V \psi_f(\text{system}) dx dy dz \right|^2 (dN_n/dE)$. The measured half-life for nuclide decay under the beta-decay process ranges from 10^{-3} s to 10^{16} years. The “valley of stability” $Q_\alpha = ((M_D + M_\alpha)/M_D)KE_\alpha \cong (\mathcal{A}_p/(\mathcal{A}_p - 4))KE_\alpha \equiv -S_{\alpha D}$ referring to the DAUGHTER NUCLEUS, p pertaining to the “parent,” KE_α the kinetic energy for the ALPHA PARTICLE, and S_α representing the separation energy for an alpha particle, with respect to the PARENT NUCLEUS.

Fermi distribution

[energy, nuclear, quantum] High temperature (T) correction for the Schrödinger EIGENVALUE potential well values (well with dimension ℓ with ENERGY $E = (\pi^2\hbar^2/2m_e\ell^2)(n_x^2 + n_y^2 + n_z^2)$): $k_i\ell = n_i\pi$, $i = x, y, z$; the WAVE number $k = 2\pi/\lambda$ for wavelength λ ; n an integer constant; $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck’s constant, and m_e the electron mass for the electrons in an “electron-gas” configuration. The correction is provided as: $F(E, T) = 1/(\delta + e^{\alpha_F} e^{((E - E_0)/k_b T)})$, with the Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23}$ m²kg/s²K; classical (BOLTZMANN) DISTRIBUTION $\delta = 0$, $e^{\alpha_F} = N = \int_0^\infty n(E) dE$ the total number of particles; for bosons $\delta = -1$, $\alpha_F = NB$ derived from the NORMALIZATION $\int P(E) dE = 1$; for fermions $\delta = +1$, $\alpha_F = NB$. It is also known as Fermi PROBABILITY distribution (see Figure F.16).

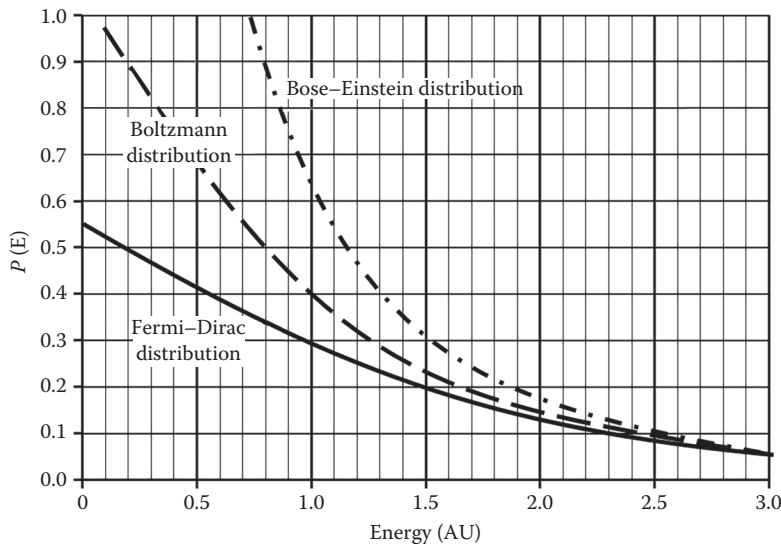


Figure F.16 Graphical representation of the difference between the Bose–Einstein distribution, the Boltzmann distribution, and the Fermi–Dirac distribution.

Fermi energy (E_F)

[atomic, chemical, general, quantum, solid-state] ENERGY gap between the unoccupied states of electron orbital configuration in the BOHR ATOMIC MODEL from the occupied orbital energy bands in atomic and molecular structure. The Schrödinger equations provide the tools to calculate the atomic and molecular energy levels that are available to bring electrons in a state that will allow them to move freely in a volume of medium made up of a single ELEMENT or a mixture. Schrödinger's conditions will quantize these energy levels for electrons. In the Bohr model, each energy level can be occupied by two fermions, where both will have opposite SPIN (spin up vs. spin down). At ABSOLUTE ZERO, all ATOMIC ENERGY levels are filled reaching a system energy for the element that is referred to as the CHEMICAL POTENTIAL as well as the Fermi energy. For an electron in a box with equal side (cube), the energy levels can be defined as $E_n = (\pi^2 \hbar^2 n^2 / 2m_e \ell^2) = E^*$, where $n^2 = n_x^2 + n_y^2 + n_z^2$, $\hbar = h/2\pi$ with $h = 6.6260755 \times 10^{-34}$ Js the Planck's constant, n are the filled energy levels, m_e the electron mass, and ℓ the length of the sides (also referred to as the depth of the POTENTIAL WELL). In terms of Fermi energy levels this can be rewritten at the Fermi QUANTUM numbers n_F , $E_F = (\pi^2 \hbar^2 n_F^2 / 2m_e \ell^2) = 3^{2/3} (\pi^{4/3} \hbar^2 / 2m_e) (N/V)^{2/3}$, with the volume of charges $V = \ell^3$ and the respective number of electron states operating at energy lower than E^* , $N = (\ell^3 / 3\pi^2 \hbar^3) (2m_e E^*)^{3/2}$, defining $n_{\max} = (\ell / \pi \hbar) (2m_e E^*)^{1/2}$. The Fermi energy indicates the occupancy cut-off for the Fermi–Dirac system, under conditions of $T = 0$ (also see CHEMICAL POTENTIAL) (see Figure F.17).

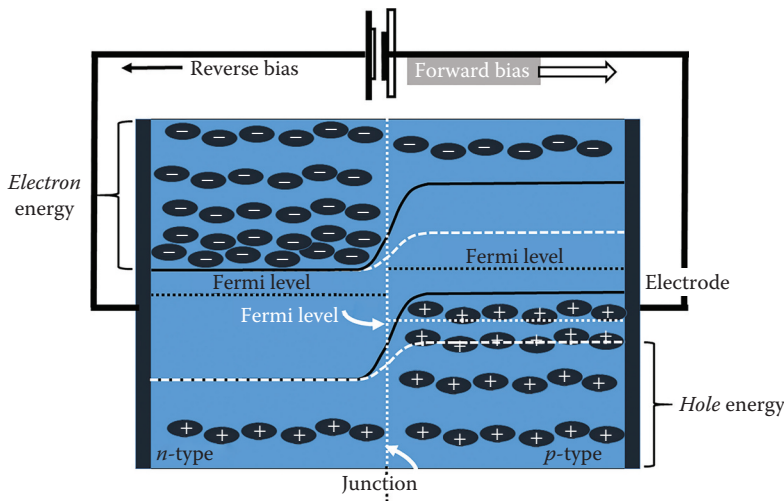


Figure F.17 The shift in Fermi energy for a semiconductor material pn -junction under forward bias (white) with respect to reverse bias (black). The pn -junction indicates semiconductor material doped with electrons for the n material, and depleted of electrons in the p material.

Fermi function

[nuclear] The penetrability with respect to a POTENTIAL BARRIER, resulting from nuclear and Coulomb forces, $V = 2e^2 Z_D / r$, Z_D the PROTON number (atomic number) for all the charges within the barrier boundaries of the daughter, $e = 1.60217657 \times 10^{-19}$ C the electron charge, and r the radius from the center of the NUCLEUS. The PROBABILITY for penetration is described as $P_F \approx e^{-\gamma_F}$, where $\gamma_F = (2/\hbar) \int_R^b [2M_0 ((\hbar^2 Z_D / r) - Q_\alpha)]^{1/2} dr$ and $M_0 = M_\alpha M_D / (M_\alpha + M_D)$ represents the REDUCED MASS due to recoil and b the “barrier thickness.” Where the DECAY time correlates as $\tau_F \approx (v_{in} / R) P_F$, with v_{in} the velocity of the ALPHA PARTICLE inside the PARENT NUCLEUS.

Fermi gas

[atomic, computational, energy, fluid dynamics, thermodynamics] Collective of fermions. Fermions are named after ENRICO FERMI (1901–1954), and are particles that are conforming to the Fermi–Dirac statistical distribution. The FERMI GAS is the simplistic approach to free electron description in a CONDUCTOR. In a Fermi gas, the lowest possible ENERGY corresponds to zero kinetic energy, whereas for a standard METAL with free electrons the lowest energy state resides at the “bottom” of the CONDUCTION BAND.

Fermi hole

[energy, nuclear, quantum] QUANTUM mechanical description of the electron and specifically the lack of electron locations in a many-atom system. The ENERGY configuration is bound by Pauli’s EXCLUSION PRINCIPLE. In particular the occurrence of paired electrons with parallel SPIN will interact with other electrons by means of repulsion, making the “seated” electrons part with their respective energy configuration. Additionally, these electrons with parallel spin will repel each other, forming what is known as Fermi holes; hence reducing the repulsive force between them. Nevertheless, all electrons are equal and indistinguishable, rendering the concept convoluted. In contrast, electrons traveling in pair possessing opposing spin will group together, forming what is known as an “electron heap.” For Helium ($1s2p$), this can be described as a WAVEFUNCTION (Schrödinger SOLUTION) with spatial antisymmetry (Fermi hole), splitting the wavefunction in a spatial part (Ψ_0) and a spin part (Ψ_s), $\Psi_{\uparrow\uparrow} = \Psi_0\Psi_s = [1s(1)2p(2) - 1s(2)2p(1)] \times [\uparrow(1)\uparrow(2)]$, compared to the antisymmetric situation (Fermi heap) with spin antisymmetry, $\Psi_{\uparrow\downarrow} = [1s(1)2p(2) + 1s(2)2p(1)] \times [\uparrow(1)\downarrow(2) - \uparrow(2)\downarrow(1)]$.

Fermi level

[atomic, general] Both for the electron SHELL MODEL of the ATOM as well as the PROTON and NEUTRON configuration in the NUCLEUS, the highest occupied level, with respect to the associated kinetic ENERGY in the waveform fitting that orbital design. Electrons can occupy the same state for at most two electrons, provided their SPIN is in the opposite direction. For the nucleons the shells are defined by the DE BROGLIE WAVELENGTH (“circumference” to be a match to a multiple of wavelengths), with a grouping of closely separated energy levels forming one shell. Under QUANTUM mechanical considerations, these shells are constructed of a system of closely separated subshells. The major shell are spaced farther apart as was described by MARIA GOEPPERT-MAYER (GÖPPERT) (1906–1963) and JOHANNES HANS DANIEL JENSEN (1907–1973) in 1947. The standing WAVE fitting the orbit conforms to a QUANTUM NUMBER. Neutrons and protons do not influence each other’s energy configuration and can share the same states, while at most two protons and two neutrons can occupy the same state. When the respective major shells are filled the atomic nucleus is more stable than when not, such as the filled configuration for Tin with 50 protons and 50 neutrons, can support 10 stable isotopes.

Fermi quantum number (n_F)

[atomic, energy, nuclear] Dimensional expression for the “radius” of a sphere ($\bar{n}_F$) in k -SPACE ($k = 2\pi/\lambda$ for wavelength λ of the Schrödinger WAVEFUNCTION) that contains all ENERGY states, with MAGNITUDE: $n_F = (3N/\pi)^{1/3}$, using the respective number of electron states operating at energy lower than E^* , $N = (\ell^3/3\pi^2\hbar^3)(2m_e E^*)^{3/2}$, where an electron in a box with equal side (cube, with ℓ the length of the sides; the depth of the POTENTIAL WELL) the energy levels can be defined as having energy $E_n = (\pi^2\hbar^2 n^2/2m_e \ell^2) = E^*$, where $n^2 = n_x^2 + n_y^2 + n_z^2$, $\hbar = h/2\pi$ with $h = 6.6260755 \times 10^{-34}$ Js the Planck’s constant, n are the filled energy levels, and m_e the electron mass.

Fermi shape

[atomic, energy, nuclear] Shape of the semiempirical nuclear POTENTIAL WELL density distribution: $f(r) = 1/(1 + e^{(r-R_0)/a_f})$, where r is the radius, $R_0 = r_0 A^{1/3}$ is the half-way radius (A the atomic number and r_0 the root-mean-square nuclear Fermi radius [of a uniformly charged sphere], order of femtometer), and a_f the diffuseness of the charge distribution.

Fermi sphere

[atomic, computational, energy, fluid dynamics, thermodynamics] In QUANTUM THEORY all particles, including atoms and molecules, can be considered as fermions or bosons. The Fermi sphere describes the ENERGY outline in k -SPACE for fermions (see FERMION SURFACE).

Fermi surface

[atomic, computational, electronics, quantum, solid-state] Concept used with respect to “density of states” relating to electron charges in conductive solids and liquids, defined in the k -SPACE (wave number space). Every conceivable state of the electrons is defined in reference to the three vector components of the WAVE NUMBER ($k = 2\pi/\lambda$, where $\lambda = c/v$ the wavelength for the WAVEFUNCTION, c the speed of light, and v the frequency). The electrons will fill all the energies to the Fermi ENERGY when at ABSOLUTE ZERO temperature, using the Fermi–Dirac distribution for half-integer SPIN particles, with momentum $p = \hbar k$, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck’s constant. The total number of electrons (N) will occupy a volume in k -space with radius: $k_F^3 = 3\pi^2 N$, defining the spherical surface outline. Thus the FERMION SURFACE is a sphere with radius k_F . The polyhedron that outlines the Fermi surface is referred to as the Brillouin zone. The Brillouin zone defines the Bragg REFLECTION planes, the periodic crystalline LATTICE planes structure providing a diffraction structure for the electron waves. Additional reference to the BRILLOUIN ZONE may also be required for full definition (see Figure F.18).

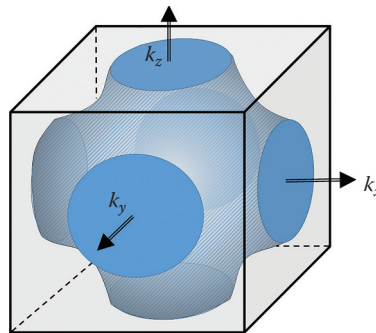


Figure F.18 Representation of the Fermi surface for a simple cubic atomic lattice.

Fermi wavevector (k_F)

[solid-state, thermodynamics] In a one-dimensional electron gas there are free electrons that can roam freely through a material (CONDUCTOR). The Fermi wavevector determines the Fermi ENERGY (ϵ_F) of the electron gas as $\epsilon_F = (\hbar^2/2m)(N_0\pi/2L_e)^2 = (\hbar^2/2m_e)k_F^2$, where L_e is the length of the electron chain at the FERMION SURFACE, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck’s constant, N_0 the total number of electrons, m the PARTICLE mass (i.e., electron; m_e), and the Fermi wavevector: $k_F = (N_0\pi/2L_e) = N_e\pi$, where N_e is the total number of electrons per unit length per SPIN direction. The density of spin states for one spin direction is $n(\epsilon) = (L_e/\pi\hbar)\sqrt{m_e/2\epsilon_F} = L_e/\pi\hbar v_e$, where the electron speed follows from $v_e = \hbar k_F/m_e$, $k_B = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the Boltzmann coefficient.

Fermi workfunction

[atomic, computational, energy, fluid dynamics, thermodynamics] The MINIMUM ENERGY requirement to satisfy the removal of an electron from a solid when residing at the Fermi energy level. $W_F = E_v - E_F$, with E_v the energy of the electron at rest once removed from the solid (VALENCE energy) and Fermi energy within the solid $E_F = \pi^2 \hbar^2 n_F^2 / 2m_e \ell^2$, $\hbar = h/2\pi$ with $h = 6.6260755 \times 10^{-34}$ Js the Planck's constant, n is the filled energy levels, m_e the electron mass, and ℓ the length of the sides of the WAVE number space (also referred to as the depth of the POTENTIAL WELL), and the Fermi QUANTUM numbers n_F (also see WORKFUNCTION).

Fermi–Dirac statistics

[atomic, nuclear] Statistical description of the ENERGY configuration for a nuclear system that conforms to the PAULI EXCLUSION PRINCIPLE. The statistical description was introduced by ENRICO FERMI (1901–1954), with corrections by P. Dirac, incorporating the fact that the total WAVE function (i.e., SOLUTION to the SCHRÖDINGER EQUATION) may also be antisymmetric. For a system of n_i occupation levels with associated PARTICLE ENERGIES ϵ_i , with g_i respective nondegenerate QUANTUM states (only one particle allowed per state, respectively two when considering the SPIN condition; consequently $n_i \leq g_i$) the PROBABILITY of finding the respective energy levels occupied is given as $W_p = \prod_i (g_i! / (g_i - n_i)! n_i!)$, note that $\sum n_i = N$ the total number of particles, and $\sum n_i \epsilon_i = E$ the total energy. This also yields the FERMI DISTRIBUTION defined as $n_i = g_i / (\mathcal{A}^{-1} e^{\epsilon_i / k_B T} + 1)$, as a function of (absolute) temperature T , with the Boltzmann coefficient $k_B = 1.3806488 \times 10^{-23}$ m²kg/s²K, and $\mathcal{A}$ a constant derived from the energy constraints. Compared to the BOLTZMANN DISTRIBUTION, this is written as $W_p^B = \prod_i g_i^{n_i} / n_i!$ (see Figure F.19).

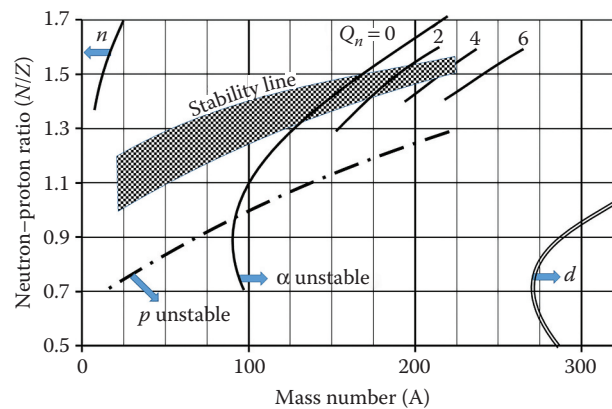


Figure F.19 Graphical representation of Fermi decay.

Fermi–Pasta–Ulam problem

[computational] Apparent paradox in QUANTUM MECHANICS and chaos theory with regard to the definition of LATTICE oscillations and the respective periodic behavior, based on the contributions from ENRICO FERMI (1901–1954; Italy–the United States), JOHN R. PASTA (1918–1984; the United States), and STANISŁAW MARCIN ULAM (1909–1984; Austria/Hungary/Poland–the United States; “inventor” of the MONTE CARLO METHOD), introduced in 1953. The computational analysis of an OSCILLATION introduced nonlinear terms with quadratic and cubic components with respect to a “vibrating string.”

Fermion

[atomic, general, quantum, solid-state] Class of particles that obeys the FERMI–DIRAC STATISTICS, including the electron, PROTON, NEUTRON, and NEUTRINO (BARYONS). This confines the SPIN to half-integer values only, in contrast to bosons with whole integer spin (e.g., ALPHA PARTICLES and PHOTON).

Ferrite

[general] Conductive materials, primarily labeled as the oxides of magnesium, zinc, manganese, or nickel. Note that the ELEMENT iron is ferrum ($^{56}_{26}\text{Fe}$). Ferrites are used to form permanent magnets based on their inherent EDDY CURRENT composition. Aligning the eddy currents by means of an externally applied electric field will transpose the medium in a PERMANENT MAGNET. Ferrites are also popular in TRANSFORMER CORES and SOLENOID-based mechanisms as the MAGNETIC FIELD confining medium (see [Figure F.20](#)).



Figure F.20 Ferrite example, clamp on signal cable to reduce noise on the line (e.g., found on computer monitor cables).

Ferroelectric

[electronics, material] Material property describing the electric properties of a medium that behave in similar fashion to ferromagnetic for MAGNETISM. Ferroelectric indicates a material with high DIELECTRIC constant that can sustain permanent electrification and additionally displays electrical HYSTERESIS. Ferroelectric media are found to have an ELECTRIC DIPOLE MOMENT for the entire medium in EQUILIBRIUM STATE.

Ferromagnet

[electronics, material] IRON and iron-like substances that can be magnetized. Ferromagnetic materials are iron, cobalt, nickel, gadolinium (rare EARTH) as well as certain alloys of manganese and chromium, whereas the latter two are not ferromagnetic by themselves. Substances with properties of FERROMAGNETISM are called ferromagnetic (general) (see [Figure F.21](#)).

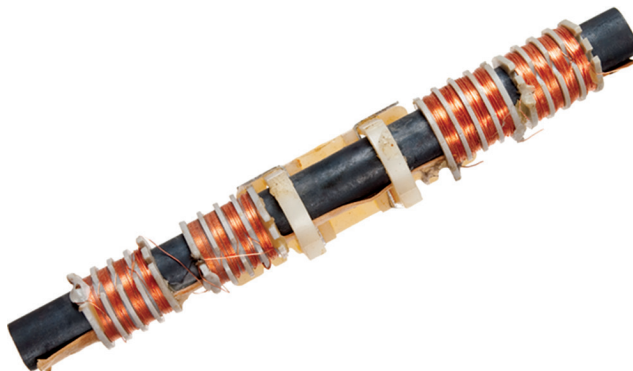


Figure F.21 Old-fashioned AM radio antenna with ferromagnet rod inside.

Ferromagnetism

[atomic, general, nuclear] Any substance with free electrons has the capability to generate local, MICROSCOPIC magnetic fields based on the MOTION of the free electrons based on the Lorentz force expressed on a moving charge and the MAGNITUDE can be found from AMPÈRE'S LAW (for a linear moving charge) and BIOT-SAVART LAW (for a circular current loop). Primarily, the orbital motion of electrons around the NUCLEUS of an ATOM in the BOHR ATOMIC MODEL has an inherent MAGNETIC FIELD. Combining the atomic fields resulting from alignment due to free electrons can produce a resultant external magnetic field. Electrons in second place possess a SPIN with associate angular momentum and linked magnetic moment. The magnetic moment of the individual electrons is oriented directly opposing the angular momentum vector due to the NEGATIVE CHARGE.

Fessenden, Reginald Aubrey (1866–1932)

[acoustics, imaging] Scientist and electrical engineer from Canada, known for the first patent on ECHOLOCATION mechanism of action in 1912, as applied to ULTRASONIC IMAGING and underwater sonar tracking (see [Figure F.22](#)).



Figure F.22 Reginald Aubrey Fessenden (1866–1932).

Feynman, Richard Phillips (1918–1988)

[atomic, energy, general, mechanics, molecular, quantum] Theoretical physicist from the United States. Dr. Feynman is best known for his popular teachings of PHYSICS and his contributions to the development of the ATOMIC BOMB. Richard Feynman uncovered several inconsistencies in the known theories

on QUANTUM ELECTRODYNAMICS and his revisions were rewarded with the Nobel Prize of Physics in 1965 (see Figure F.23).



Figure F.23 Richard Feynman (1918–1988). (Courtesy of Tamiko Thiel.)

Feynman diagram

[general, quantum, theoretical] Graphical representation of the virtual interactions between ELEMENTARY PARTICLES pertaining to QUANTUM ELECTRODYNAMICS. The illustrations are designed to elude to the basic principles of the presumed interactions, based on theoretical predictions. The “AMPLITUDE” of a PARTICLE being in a certain location can be illustrated as a vector in three-dimensional space, alternatively the associated PROBABILITY of an interaction at that location is represented by the amplitude squared. The processes for these types of constituents are convoluted and cannot be isolated as individual process, hence the “virtual process” reference. The processes of elementary particles have not been empirically established due to the limitations in current experimental technology as well as the inherent uncertainty associated with these processes based on the Heisenberg principles. Some of the better verified interactions are with respect to photon–electron interactions, photon–photon interactions, and electron–electron processes. For a given reaction, the object and interaction are all represented by amplitudes; say the migration of a PHOTON from point $\bar{x}_1$ to point $\bar{x}_2$ is represented by amplitude $B(\bar{x}_1, \bar{x}_2)$, while the undisturbed track for an electron from point $\bar{x}_1$ to point $\bar{x}_2$ is represented by amplitude $C(\bar{x}_1, \bar{x}_2)$, and associated interaction amplitude of the photon with the electron $A_{(1)} = eD$, e the electron charge. Alternatively, additional events may take place, such as the resonant interaction of the photon with the electron (for instance, in location $B(1,0)$) resulting in a “virtual” photon, which may subsequently be reabsorbed ($C(1,2)$), rendering the electron in $B(0,2)$, represented by amplitude $A_{(2)}^a = e^3 \int DB(1,0)DB(0,2)DC(1,2)$. Each occasion is referred to as a “vertex,” effectively the DEGREES OF FREEDOM of the system. The complexity may progress with additional interactions, adding additional nodes in the Feynman diagram, and resulting superposition in the amplitude integration. The total amplitude is provided by the summation of all the interaction, $A = A_{(1)} + A_{(2)} + A_{(3)}^a + A_{(3)}^b + \dots$, with associated PROBABILITY $P = |A|^2$. The potential interactions are

strong interaction, WEAK INTERACTION, electromagnetic and gravitational for regular (electron, NEUTRON, PROTON), and elementary particles (quarks, etc.) as well as RADIATION. The complexity of the Feynman diagram increases with the number of events and components (see [Figure F.24](#)).

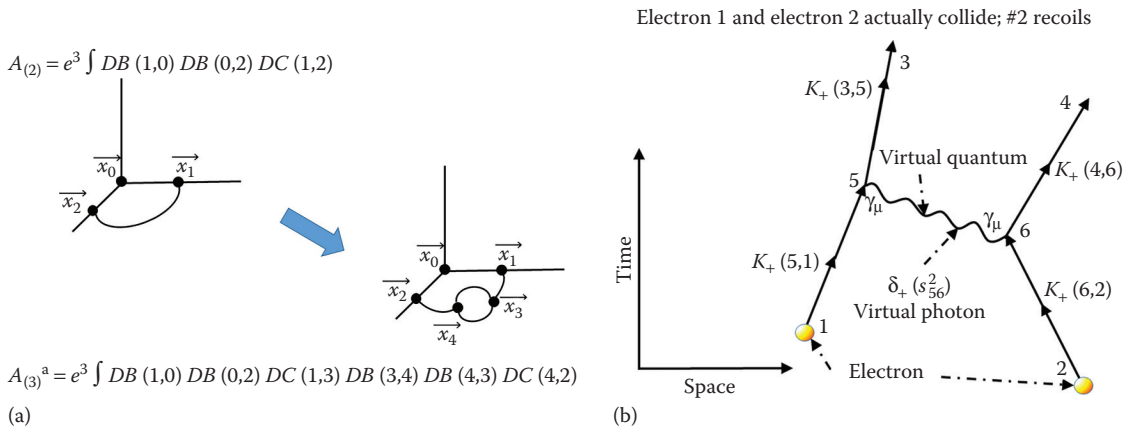


Figure F.24 (a) Feynman diagram for photon–electron interaction with reabsorption in phase 2 on the right and (b) Feynman diagram for electron collision and virtual photon emission based on the energy exchange.

FFT

[computational] See **FAST FOURIER TRANSFORM**.

f-function

[nuclear, relativistic] Gauge force space with respect to strong and weak nuclear forces. Based on the realization that NEUTRON and protons are not FUNDAMENTAL PARTICLES, but consist of quarks with strong force holding together to appear a single unit, the force gauge invariance principles can be illustrated by means of the introduction of an auxiliary force space: the f -space. The f -space is outlined as a sphere (circle). The f -function can take values between 0 and 2π (circle) without affecting the transform applied to the WAVE function: ψ (SCHRÖDINGER WAVE EQUATION SOLUTIONS); with transform $\psi'(\vec{r}, t) = e^{if(\vec{r}, t)}\psi(\vec{r}, t)$, in both space ($\vec{r}$, respectively $[x, y, z]$) and time (t). When considering the MAXWELL EQUATIONS for a four-vector field potential ($\phi_x, \phi_y, \phi_z, \phi_t$) instead of the electric (E) and magnetic (B) field, the following transformation can be applied: $\phi'_t = \phi_t + (\partial f / \partial t)$, respectively: $\phi'_{x_i} = \phi_{x_i} + (\partial f / \partial x_i)$, yielding the transformed vector field: $(\phi'_x, \phi'_y, \phi'_z, \phi'_t)$. The exponential value of the EIGENFUNCTION remains unchanged by addition of multiples (fractional values) of 2π . In order to define the gauge forces in theory a total of eight strong force f -functions are required in addition to four WEAK FORCE f -functions would be required, however due to the symmetry only one f -function coupling constant is needed instead of 12 next to coupling constant for the weak force and one additional for the strong force; three total. This becomes more evident when considering the Yang–Mills theory of the NUCLEAR FORCE.

Fiber-optic

[general, optics] A light conduit concept that is based on TOTAL INTERNAL REFLECTION principles. The general concept of the fiber-optic is a transparent, round core surrounded by another transparent medium with a lower index of REFRACTION (n_i), the “cladding” (ensuring the conditions for perfect grazing incidence reflection). The outside shell is providing a protective layer and is referred to as the jacket. Fiber-optic diameter ranges from a few micrometer to several hundred micrometer. The larger the fiber-optic core diameter, the more rigid the fiber structure, with increasing bending radius. A 100- μm fiber-optic will have a bending radius in the order of 2 cm, whereas a 5- μm fiber-optic can be wrapped in a radius of a few millimeter. The transmitting medium can be made of various materials, while high-end fiber-optics use silica GLASS or fused silica for both the core and the cladding,

while the jacket is made of plastic or acrylic materials and in some cases a varnish. The transmission of light with the reflective aspects at respective interfaces with different index of refraction can be described by solving the MAXWELL EQUATIONS for both the ELECTRIC FIELD (E) and the MAGNETIC FIELD (B). At the interface between two layers of different index of refraction, the electric field is confined by the following conditions: (1) the electric field needs to be perpendicular to the interface, or the electric field is zero on a conducting WALL (specifically for a hollow waveguide) and (2) in the direction of propagation the magnetic field is restricted to being parallel to the interface. Considering the waveguide in first-order approximation for small segments of the conduit with CARTESIAN COORDINATES, z is the direction of propagation, y is the radial direction toward the core, and x is the direction of the circumference parallel to the surface the general solutions are a transverse electric field and a transverse magnetic field, respectively. The transverse electric field SOLUTION with WAVE numbers $k_i = 2\pi/\lambda_i$, where $\lambda = c/v = c/(\omega/2\pi)$ (speed of light $c = \sqrt{\mu_0\epsilon_0}^{-1/2} = (\mu_0\epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s in VACUUM, for the medium the VELOCITY (v) is restricted by the index of refraction as $n = c/v$; ν the frequency, ω the ANGULAR FREQUENCY, and λ the wavelength) represents the wavelength (illustrating the confinement as well as DISPERSION in directional propagation, with disparity in group velocity and PHASE VELOCITY), defined by an electric field $E_z = -(k_y/k_z)E_0 \sin(k_y y) \sin(\omega t - k_z z)$, $E_y = E_0 \cos(k_y y) \cos(\omega t - k_z z)$, and $E_x = 0$, and magnetic fields $B_z = B_y = 0$ and $E_y = (\omega/k_z c^2)E_0 \cos(k_y y) \cos(\omega t - k_z z)$, respectively. The transverse magnetic field solution is written as $E_x = E_0 \sin(k_y y) \cos(\omega t - k_z z)$; $E_z = E_y = 0$, respectively $B_z = -(k_y/\omega)E_0 \cos(k_y y) \sin(\omega t - k_z z)$, $B_y = -(k_z/\omega)E_0 \sin(k_y y) \cos(\omega t - k_z z)$, and $B_x = 0$. Keeping in mind that the electric and magnetic fields are freely rotating as they travel along the length of the optical fiber, the Cartesian approach, including the angular component will add additional complexity. The solutions for the Maxwell equations can provide a multitude of waveforms for a large core fiber, making the solution process rather complex. In case special constraints are applied only a few or a single specific wavelength can be transmitted, with a well-defined solution for the Maxwell equations. The special case relates to the “single-mode” fiber, which is specifically designed to fit a particular laser WAVELENGTH (λ); using shorter wavelengths will provide “few” mode transmission. Generally, a fiber-optic is defined by the core diameter and the NUMERICAL APERTURE of the core design. The NUMERICAL aperture describes the maximum opening ANGLE ($\theta_{\max}$) for the collection of light, $NA = n_i \sin \theta_{\max} \cong n_i \sqrt{(n_{\text{core}}^2 - n_{\text{cladding}}^2)}$, per core index with external index of refraction n_r . Because of the confined space in the diameter of the transparent rod the light will be interfacing at an angle of incidence greater than the critical angle, hence providing perfect REFLECTION. Generally, large core fibers are multimode, describing the loss of any phase-related information of a coherent beam of light due to multiple paths with various lengths that provide “mode-scrambling.” A special format of fiber-optic is the *single-mode fiber*, which is designed to provide PHASE velocity-confined transmission, hence the light emitted on the distal end will be in full coherent synchronicity with the light entering on the proximal side of the fiber-optic. Based on the solutions to the Maxwell equations, the transmitted waveforms are restricted to the LP_{01} (linearly polarized mode of order 1; approximate), or respectively the exact HE_{11} mode (“helical” path, with respect to a skew ray; H indicating the magnetic field and E the electric field mode, hence primary wave only) only. The quality of a single-mode fiber-optic is described by the V -number: $V_n = k a_r NA$, with $k = 2\pi/\lambda$ the wave number and a_r the fiber core radius. For instance, $V_n < 2.405$ defines an appropriate value for a single-mode fiber, defining the “cut-off” wavelength λ_c . Generally, the core diameter is also restricted to only a few. The total number of guided modes is derived as $M_{\text{guided}} \approx (V_n^2/2)$ (which can amount to several thousands for a multimode fiber). Single-mode fibers are particularly useful for coherent imaging, for example, OPTICAL COHERENCE TOMOGRAPHY (OCT). Coupling light into a multi-mode fiber-optic is relatively easy, whereas a single-mode fiber-optic has specific requirements that need to be satisfied for efficient and low loss coupling; focusing the waist of the laser beam to at least within 110% of the core diameter, while simultaneously considering the numerical aperture (angle of incidence) requirements for the fiber-optic. One specific application is the use of a graded index of refraction for the core of the optical rod. The graded index of refraction (GRIN) provides a means of focusing the light, hence increasing the preservation of the phase and AMPLITUDE features of the light, avoiding dispersive distortion. The graded index can be step-wise or continuous/smooth. The optical path in a GRIN fiber is defined through SNELL’S LAW; WILLEBRORD SNEEL VAN ROYEN (1591–1626). The increases in requirements for fiber-optic communications and data transmission have resulted in the introduction of high-quality graded-index POLYMER optical fibers (PLASTICS). An alternative approach is the use of a hollow fiber, for instance, a glass or polymer tube coated with reflective material, specifically geared to the transportation of INFRARED and ULTRAVIOLET light where most glass, plastic, and semiconductor media (silicon, germanium,

phosphorus) have limited transmissivity and may hence result in substantial wavelength-dependent attenuation per unit length. Fiber quality is generally indicated by the attenuation per unit length in logarithmic form (dB/m). Fiber-optics operating in the ultraviolet require a high water content (“high OH,” e.g., used for Excimer laser operating in the 308 nm range), whereas infrared transmission requires low water content (“low -OH”). Splicing refers to the process of joining two fiber-optic fibers together. A mismatch in core and/or cladding dimensions will result in coupling losses. The arrangement of a bundle of fibers for IMAGE transfer needs to have a one-to-one correlation between the input and output locations of the fibers, and is referred to as a coherent bundle. When the fibers are randomly arranged the bundle is said to have an incoherent configuration, generally applies to ENERGY transfer (e.g., fiber-optic catheter for atherectomy; plaque removal from BLOOD vessels). Applications of fibers are in imaging systems (endoscopes and safety/quality inspection for commercial/industrial use), clinical therapeutic devices (catheters: atherectomy, laser treatment of cardiac arrhythmias [irregular HEART rate]; lithotripsy [breaking-up KIDNEY stones]; interstitial cancer treatment, and many more), as well as industrial applications for cutting and a significant amount of fiber-optic cabling is used for optical communications (digital as well as coherent). For some applications the use of LIQUID light guides can be preferred due to the large core and hence substantial potential for light transmission. The liquid LIGHT GUIDE uses a liquid core rather than a solid plastic or glass core, capped on either end with a solid optical rod. Liquid light guides are, for instance, used for illuminating the sample under a MICROSCOPE next to the illumination of a surgical site as a headlamp for a surgeon and in automotive repairs for inspection of engines and other hard to reach places (see Figure F.25).

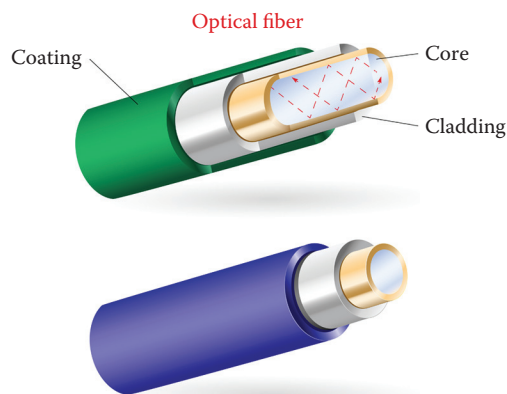


Figure F.25 Illustrations of fiber-optic light guide designs and applications.

Fibonacci sequence

[atomic, biomedical, chemical, computational, general, quantum] Number sequence. The number sequence is found in many biological events and conditions, such as the idealized population EXPANSION for mice or rabbits, next to the geometric structure of a snail shell, the branches of a tree, and many more phenomena as well as computational applications. Certain chemical compositions are formed based on the Fibonacci sequence, specifically uranium and chromium oxides next to other chemical chains; additional examples are found in LATTICE structures for crystals and some may say that the electron arrangement of an ATOM in internal transitions follows a Fibonacci sequence. The number sequence is defined starting out with zero and one and the subsequent numbers are found by adding the last number to the number before that: 0, 1, 1, 2, 3, 5, 8, ...; formally introduced in 1202. Even though the history of this number series can be traced back to Pingala (scientist from Asian/Arabic geographic location; India). Pingala lived approximately in the second century BC, associated with the formal introduction of a binary mathematical structure. There are additional rooted traces to the history of the recognition of the importance of this number sequence in Indian/Arabic mathematics well before the western calendar (“before Christ”). The NUMERICAL sequence is named after the mathematician from Italy attributed with official documented applications: LEONARDO PISANO BIGOLLO (c. 1170–1250), whose alias was “Fibonacci,” also known as Leonardo Pisano, or Leonardo Fibonacci.

Fick, Adolf Eugen (1829–1901)

[biomedical] Physiologist from Germany, known for his contributions in osmotic GAS exchange and the calculation of CARDIAC OUTPUT. Other contributions to modern MEDICINE by Fick were in ANESTHESIOLOGY (see [Figure F.26](#)).



Figure F.26 Adolf Fick (1829–1901). (Courtesy of Anton Klamroth in 1897.)

Fick, Adolf Gaston Eugen (1852–1937)

[biomedical, optics] Physiologist and physician from Germany who has on record developed the first contact LENS (see [Figure F.27](#)).



Figure F.27 Adolf Gaston Eugen Fick (1852–1937).

Fick's equation

[biomedical, chemical, computational] Description of the migration of small molecules across a BARRIER that can be chemical, mechanical, or electrical (POTENTIAL BARRIER), primary concepts were developed by ADOLF EUGEN FICK (1829–1901). It is also known as Fick's first law (see [DIFFUSION EQUATION](#)).

Fine structure

[atomic, energy, optics, solid-state] An electron in orbit around the atomic nucleus will perform PRECESSION around an applied external MAGNETIC FIELD in discrete configurations. The number of discrete magnetic moments is defined by the ORBITAL MAGNETIC QUANTUM NUMBER m_ℓ . The orbital QUANTUM NUMBER ranges in integer values from negative ORBITAL ANGULAR MOMENTUM QUANTUM NUMBER (ℓ) to positive value (where ℓ has values between 0 and $n-1$, n being the PRINCIPAL QUANTUM NUMBER). The split in configuration with respect to the absence of an external field provides a multitude of spectral lines within close values of the natural state. This split in spectral lines is referred to as the fine structure. The fine structure ENERGY configuration (E_{fs}) can be derived to be as follows, specifically for the HYDROGEN ATOM: $E_{fs} = -(hcZ^2R/n^2)\{(\alpha_{\text{fine}}Z^2/n)[1/(j_d + 1/2) - (3/4n)]\}$. With PLANCK'S CONSTANT $h = 6.626070040(81) \times 10^{-34} \text{ m}^2\text{kg/s (Js)}$, FINE STRUCTURE CONSTANT ($\alpha_{\text{fine}} = (e^2/4\pi\hbar c) = 1/137$), j_d the "DOUBLET" split for the angular momentum: $j_d = \ell + (1/2)$; $j_d = \ell - (1/2)$ (Note: for $\ell = 0$ only $j_d = \ell + (1/2)$ is allowed.), $R = 10973731.6 \text{ m}^{-1}$ the RYDBERG CONSTANT, Z the ELECTRIC CHARGE for the NUCLEUS, and $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of light. When the nuclear magnetic moment becomes involved, the spectral profile splits into HYPERFINE STRUCTURE (also see ZEEMAN EFFECT) (see Figure F.28).

F

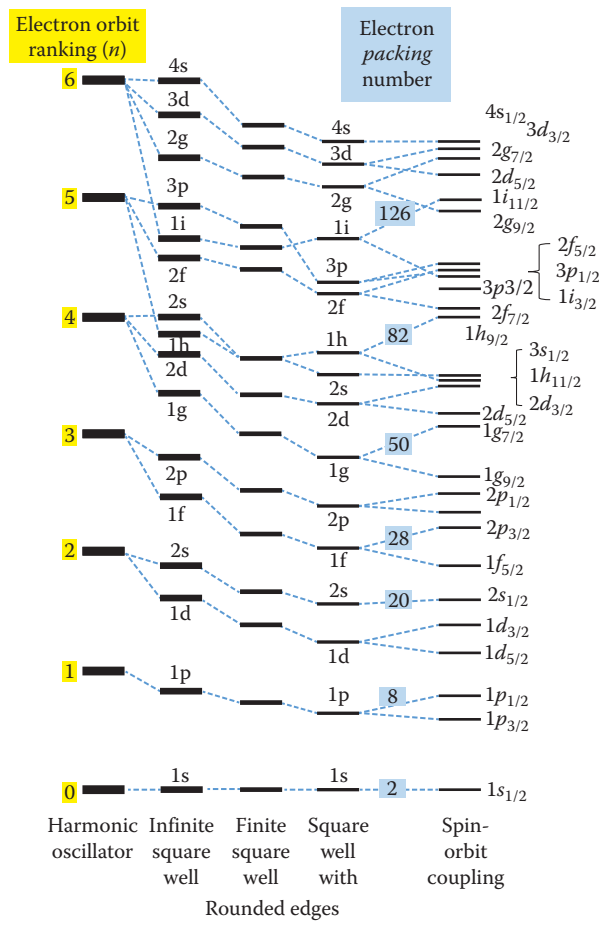


Figure F.28 Finely split structure of the electron orbit under autonomic conditions. The diagram illustrates the impact of the choice of energy model for the nuclear potential on the electron configuration, while obeying all exclusion laws.

Fine structure constant ($\alpha_{\text{fine}} = (e^2/4\pi\hbar c) = 1/137$)

[atomic, general, quantum] Dimensionless quantity used in description of the QUANTUM theoretical description of the atomic events, where $\hbar = h/2\pi$ is PLANCK'S CONSTANT $h = 6.626070040(81) \times 10^{-34} \text{ m}^2\text{kg/s (Js)}$ divided by 2π , c the speed of light, and e the electron charge. In quantum ELECTRODYNAMICS, α_{fine} represents the electromagnetic coupling strength. The FINE STRUCTURE constant relates to Coulomb's law ($F_e = q_1q_2/4\pi\epsilon_0r^2$, where q_1 and q_2 are the respective charge in value of Coulomb, $\epsilon_0 = 8.8541878 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the DIELECTRIC permittivity in VACUUM, and r the separation between the centers of the two charge concentrations, respectively).

Finesse ($\mathcal{F}$)

[fluid dynamics, optics] Qualification factor for an optical cavity, alternatively in AERODYNAMICS it defines the ANGLE of the AIRFOIL with respect to the FLUID stream (in aviation; the glide ratio) and resulting LIFT potential. Examples of *optical* cavities this applies to are Fabry–Pérot étalon pertaining to INTERFEROMETER construction. Finesse defines the ratio between the “FREE SPECTRAL RANGE” (FSR; $FSR = c/2L$, c the speed of light, L characteristic length for the phenomenon) and the “full-width half-maximum” (FWHM) of the beam, respectively, resonator. The FSR is the wavelength spacing for the maxima or minima created by two wavelengths in REFLECTION or transmission. Finesse is described by the parameter: $= FSR/FWHM$; high “Q” value represents “high finesse,” and low “Q” value indicates “low finesse.” The cavity is relatively short compared to a laser cavity; however, the principal goal remains filtering with respect to wavelength based on cavity configuration. In case the path length between the two reflective surfaces (often referred to as optical flats), with reflectivity R , forming the cavity has a match to a whole number of wavelengths the transmitted light will be in PHASE and amplified, whereas if out of phase destructive INTERFERENCE will provide the conditions for a minimum in transmission. Assuming the light with wavelength λ enters the étalon with refractive index n and thickness ℓ at an angle θ , the resulting phase shift after each successive reflection will be $\delta = (2\pi/\lambda)2n\ell \cos\theta$. On transmission T_{etalon} , the yields for the étalon are $T_{\text{etalon}} = (1 - R)^2 / (1 + R^2 - 2R \cos\delta) = 1 / (1 + F_{\text{finesse}} \sin^2(\delta/2))$, with $F_{\text{finesse}} = 4R / (1 - R)^2$ the coefficient of finesse. The Fabry–Pérot étalon will have several closely spaced transmission lines across the optical spectrum, separated by the free-spectral range FSR: $\Delta\lambda$, a device constant. The finesse can now be written as $\mathcal{F}_{\text{optic}} = \Delta\lambda/\delta\lambda = \pi / (2 \arcsin(1/\sqrt{F_{\text{finesse}}}))$. The flats enclosing the cavity are often shaped in the form of a wedge to avoid multiple internal reflections with the boundary. In case the reflectivity is high (> 0.6), the interference pattern will produce concentric circles that are highly visible and sharply demarcated, described by a high finesse, whereas low contrast is defined by low finesse. In *aerodynamics*, the finesse indicates the cotangent of the downward angle of the WING of a bird or plane, expressed as the ratio of forward speed (v_{forward}) and downward draft VELOCITY (v_{down}) for an unpowered airplane or soaring bird-of-prey (e.g., vulture or eagle): $\mathcal{F}_{\text{flight}} = L/D = \Delta s/\Delta b = v_{\text{forward}}/v_{\text{down}}$, where L/D is the lift over DRAG ratio, Δs

displacement, and Δh the incline of the wing. If the AIR rises faster than the downward draft or rate of sink the object will remain airborne and will in fact climb (Table F.1).

Table F.1 Examples of glide ratio—finesse in aerodynamics

OBJECT IN FLOW (FLIGHT)	CONDITIONS	L/D RATIO; GLIDE RATIO
Apollo CM	Re-entry	0.368
Gimli glider	For example, Boeing 767–200 running low on fuel	~12
Hang glider	Airborne under own lift	15
Northern flying squirrel	Floating through the air	1.98
Paraglider	High-performance model	11
Parachute that is under external power	Rectangular	3.6
	Elliptical parachute	5.6
Sail-plane	Airborne under own lift	45–70 (function of wingspan)
Space shuttle	Landing approach to earth base	4.5
Space shuttle	Hypersonic in outer space (e.g., orbit around the Moon)	1.0
Wingsuit	Drifting through atmosphere after jump	2.5

Finsen, Niels Ryberg (1860–1904)

[biomedical, optics] Physicist and physician from Iceland, Denmark. Niels Finsen received the Nobel Prize in Medicine in 1903 for his contributions to the evolution in solar therapeutic applications. Nonetheless, the benefits of sunlight to the body for general health, for therapeutic applications to SKIN diseases (e.g., acne, psoriasis as well as the treatment of rubella), and general benefits to mood were known for millennia by the Egyptians, and healers in India and China. The photodynamic therapy applications for rubella (mumps) and smallpox was described by the physician HENRI DE MONDEVILLE (1260–1320). More in-depth work on photodynamics interaction was described by OSCAR RAAB (1886–1986) and his work under the guidance of Hermann von Tappeiner (1847–1927) based on the PHOTOTOXICITY by Marcacci in 1888 (see Figure F.29).



Figure F.29 Niels Ryberg Finsen (1860–1904).

First law of Faraday

[atomic, general, nuclear, quantum, thermodynamics] See **FARADAY, FIRST LAW OF**.

First law of thermodynamics

[biomedical, energy, general, nuclear, solid-state, thermodynamics] That the change in the **INTERNAL ENERGY** (U) of a system is the net result of the **HEAT** (Q) added to, or removed from, the system and the work (W) done by the system on the surroundings as given by $\Delta U = \Delta Q - \Delta W$. The work done can be mechanical (W_M), and/ or electrical (W_{elec}) (*also see* **THERMODYNAMICS, FIRST LAW**). The **LAWS OF THERMODYNAMICS** were introduced by **JOSIAH WILLARD GIBBS** (1839–1903), **RUDOLF JULIUS EMANUEL CLAUSIUS** (1822–1888), **HERMANN LUDWIG FERDINAND VON HELMHOLTZ** (1821–1894), **NICOLAS LÉONARD SADI CARNOT** (1796–1832) and **PETER GUTHRIE TAIT** (1831–1901).

First postulate of relativity

[general] All laws of **PHYSICS** are identical with respect to the uniformly advancing observer. This **PRINCIPLE OF RELATIVITY** was introduced by **ALBERT EINSTEIN** (1879–1955).

Fission

[nuclear] Primarily referring to **NUCLEAR FISSION**, the splitting of the atomic nucleus into smaller **ISOTOPE(s)** accompanied by **RADIATION** consisting of particles (alpha, beta, **NEUTRON**, etc.) and/or **ELECTROMAGNETIC RADIATION**. The first experimentally observed fission was in 1934, based on the work by **ENRICO FERMI** (1901–1954; in his day referred to as “The Pope” based on his “new faith” with respect to **QUANTUM MECHANICS**), where uranium bombarded by thermal neutron generated beta rays. The German chemist **IDA NODDACK** (1896–1978) postulated in 1934 that the uranium nucleus can be deconstructed into several fragments that constitute isotopes of known **ELEMENTS** with additional emissions. This concept was initially rejected by the entire **PHYSICS** community, but was confirmed through a follow-up experiment by the German/Austrian group of scientists consisting of **LISE MEITNER** (1878–1968), **OTTO HAHN** (1879–1968), and **FRIEDRICH WILHELM STRASSMANN** (1902–1980; *Straßmann*) in 1937. The term “nuclear fission” was introduced in 1938 by **LISE MEITNER** (1878–1968) and her nephew **OTTO ROBERT FRISCH** (1904–1979) in conversation with **NIELS BOHR** (1885–1962). The initial fission principles were described based on the liquid-drop atomic model of Niels Bohr and **JOHN WHEELER** (1911–2008), formally shared in 1939. Under the **LIQUID-DROP MODEL**, the introduction of a kinetic **PARTICLE** provides a perturbation, which is interpreted as a “jelly-like” **VIBRATION** (also referred to as “liquid-drop”) resulting in a separation of the blob into two or more jelly-plum-puddings (also remember the “raisin-plum-pudding” atomic model by Lord Kelvin; **WILLIAM THOMSON, 1ST BARON KELVIN** [1824–1907], and **JOSEPH JOHN THOMSON** [1856–1940]). In this model the perturbation provides the means for the repulsive forces between the similar charges within the **NUCLEUS** to take the upper hand. Additional work by Robert Frisch provided the theoretical concept for the development of the **ATOMIC BOMB** in 1940, along with a German scientist, **RUDOLF ERNST PEIERLS** (1907–1995), while both in the United Kingdom. In 1942, the first fission **REACTOR** power plant was tested by the group of Enrico Fermi in a new facility at the University of Chicago, Illinois. The **ENERGY** released by the process of nuclear fission is the net surplus with respect to the relativistic masses of all the constituents. In 1963, a more energy-based description of the fission concept was introduced by the Polish/Swedish physicist **Wladyslaw J. Swiatecki** (1926–2009), including the “**POTENTIAL BARRIER**” model of the nuclear shell, based on his investigations of fission half-lives dating back to the early 1950s. The fission process will be required to exceed a potential **BARRIER** before the attractive forces are overcome by the repulsive forces (*also see* **NUCLEAR FISSION**) (see [Figure F.30](#)).

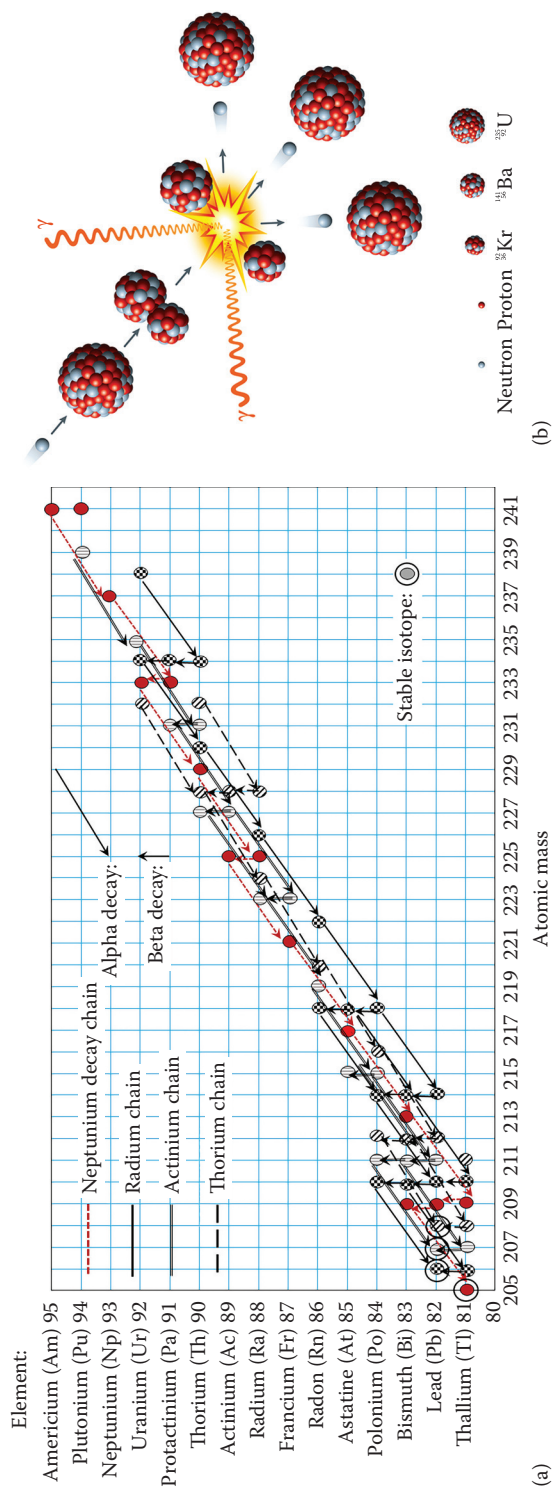


Figure F.30 Example of nuclear fission: (a) plutonium (americium) decay chain and (b) diagram of the fission process in nuclear reactors, generating electrical power as a result of steam created from the release of heat during the fission process.

FitzGerald, George Francis (1851–1901)

[atomic, general, nuclear] Physicist from Ireland. FitzGerald is most known for his collaboration with HENDRIK LORENTZ (1853–1928) for their work on the theory of special relativity and LENGTH CONTRACTION: the LORENTZ–FITZGERALD CONTRACTION (see [Figure F.31](#)).

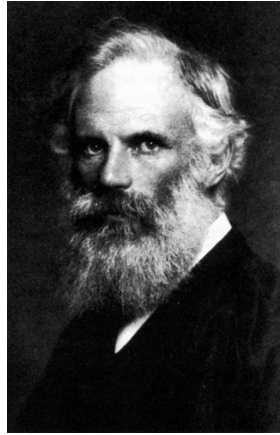


Figure F.31 George Francis FitzGerald (1851–1901).

FitzGerald–Lorentz hypothesis

[atomic] See LORENTZ–FITZGERALD CONTRACTION.

Fizeau, Armand Hippolyte Louis (1819–1896)

[general] French physicist. Fizeau made remarkable advances in the determination of the speed of light in 1849. He used a sprocket with more than 100 teeth that periodically interrupted the path of a light beam, rotating at several hundred revolutions per SECOND. Fizeau measured the time the light took to travel to and from a fixed MIRROR through the same gap between the sprocket teeth at a DISTANCE of over 8.5 km. This crude method resulted in a value for the speed of light as 3.133×10^8 m/s in AIR, which is within 5% of the accepted standard of 2.99792458×10^8 m/s in VACUUM (see [Figure F.32](#)).

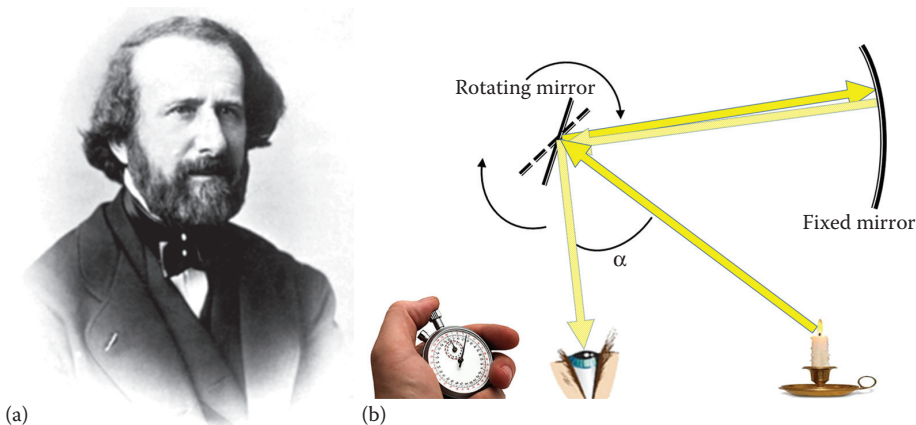


Figure F.32 (a) Armand Hippolyte Louis Fizeau (1819–1896) and (b) Fizeau's experimental design.

Flavors of quarks

[energy, general, quantum, relativistic] Designation of the “attitude” of a QUARK as proposed by MURRAY GELL-MANN (1929–) and GEORGE ZWEIG (1937–). There are six flavors: up, down, strange, charmed, beauty (or bottom), and top (see [Figure F.33](#)).

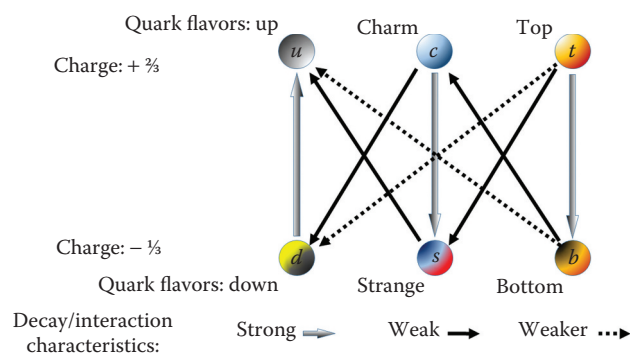


Figure F.33 The flavors for quarks.

Fleming, John Ambrose, Sir (1849–1945)

[electromagnetism, solid-state] English physicist and electrical engineer. Fleming laid the foundation for the VACUUM tube in 1907. Fleming’s work inspired the development of the RADIO transmitter by GUGLIELMO MARCONI (1874–1937). Sometimes referred to as the “father of modern ELECTRONICS” (see [Figure F.34](#)).



Figure F.34 John Ambrose Fleming (1849–1945) in 1890. (Courtesy of JDR, *Electrical World*, vol. XLV, no. 10, McGraw-Hill, New York, 1890.)

Fleming's right-hand rule

[electronics, general, mechanics] Right-hand rule as introduced by the physicist SIR JOHN AMBROSE FLEMING (1849–1945) from the United Kingdom (see RIGHT-HAND RULE) (see [Figure F.35](#)).

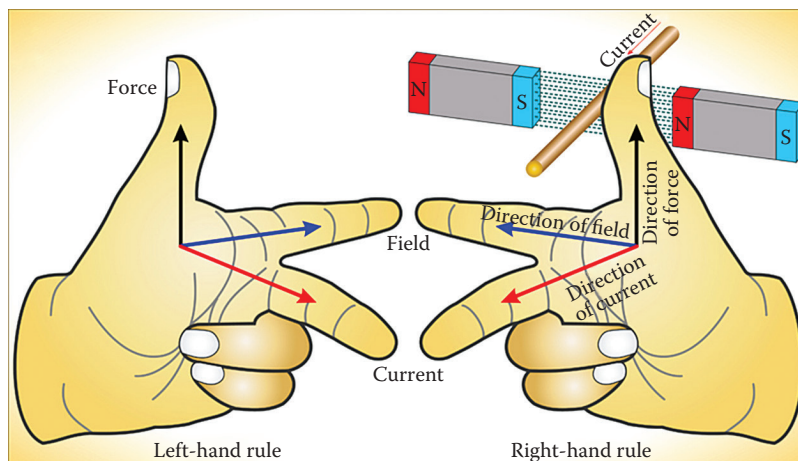


Figure F.35 Fleming's right- and left-hand rule.

Fletcher, Harvey (1884–1981)

[general] Physicist from the United States and student of ROBERT MILLIKAN (1868–1953), who systematically analyzed thousands of charged droplets to provide the electron charge in the Millikan OIL-DROP EXPERIMENT. Additional work by Harvey Fletcher was in audio and ACOUSTICS, specifically stereophony (sometimes referred to as the “father of stereophonic sound”) (see [Figure F.36](#)).



Figure F.36 Harvey Fletcher (1884–1981) on Y mountain, Utah, in 1912.

Flow

[acoustics, fluid dynamics, general] Flow is characterized as fluids in MOTION with specific features which were first defined by LEONHARD EULER (1707–1783). Each point within the FLUID can be defined and is associated with a range of physical parameters as a function of time and location. Some physical parameters are VELOCITY (v), DIRECTION ($\vec{s}$), MASS (m), DENSITY (ρ), and PRESSURE (P). Flow can be under specific conditions; examples of flow conditions are steady and nonsteady, compressible and incompressible, rotational and irrotational, as well as viscous and nonviscous. Each flow condition is subject to specific boundary conditions. The path along which fluid flow is known as a streamline. Under steady flow, at every point in the fluid the velocity is independent of time, while the opposite is true for nonsteady, or turbulent, flow. When a fluid in motion has a density that is independent of position and time it is incompressible, which holds true for most liquids, whereas gasses can have a variable density in both time and place under flow and are considered compressible. Rotational flow is characterized by changing directional flow, such as seen in whirlpools and tornadoes, in contradiction to IRROTATIONAL FLOW with parallel, or diverging respectively converging streamlines, but no rotational flow patterns. In case frictional forces are influencing the streamlines, the fluid exhibits VISCOSITY (i.e., viscous flow) whereas an ideal fluid is nonviscous or frictionless. Fluid flow is generally governed by the EQUATION OF CONTINUITY next to BERNOULLI'S EQUATION (see [Figure F.37](#)).



Figure F.37 General flow representation.

Flow, pulsatile

[biomedical, computational, fluid dynamics] Pulsatile FLOW can present in many different formats, the BLOOD flow is one of the more complex expressions. The HEART beat and resulting flow generates a complex flow rate pattern, as illustrated in [Figure F.38](#). FOURIER ANALYSIS of this SIGNAL will show that the WAVE pattern can be approximated by the first eight sinusoidal harmonics, with the base wave the heart rate. The frequency-dependent flow requires the introduction of a frequency component in the flow parameter. Using the axial flow $u(r)$ as the base for steady-state flow, the frequency-dependent flow can be developed in a harmonic EXPANSION with the use of a Poisson series and can be described as $u(r) = u'(r)e^{i\omega_n t}$, where ω_n the angular frequency harmonics for the pulsating flow driven at frequency ν . Substitution of the time-dependent harmonically oscillating flow in the POISEUILLE FLOW equation provides the FLUID dynamic equivalent of the TELEGRAPH EQUATION for wave transmission as the real value of the complex SOLUTION described by Bessel function of the first order $J_0(x)$: $u(r, t) = \text{Re} \left\{ -(ia_n/\omega_n)e^{i\omega_n t} \left[1 - (J_0(\sqrt{-i\alpha}(r/R))/J_0(\sqrt{-i\alpha})) \right] \right\}$, where the pulsatile flow can be developed in a FOURIER SERIES with coefficients a_n for the harmonic contributions, $\alpha^2 = ReSr$, Re the REYNOLDS NUMBER, and $S_r = \omega D/\nu_{\text{avg}}$ the Strouhal number, where ν_{avg} the average flow velocity and $D = 2R$ the vessel diameter. The Strouhal number is the ratio of the TURBULENCE-induced fluidic forces over the internal forces rendering local accelerations within the velocity profile. The Strouhal number is critical in estimating the timescale for formation of VORTEX flow. The Strouhal number provides a determining factor in the contribution for the respective frequency parameters. Thus the flow velocity profile is critically linked to the vessel diameter, PUMP frequency, and flow rate. For small α (long timescale for turbulence), the flow velocity becomes parabolic under steady-state Poiseuille flow, $u(r, t) = a_n \{ [1 - (r^2/R^2)] \cos(\omega_n t) \}$ (see [Figure F.38](#)).

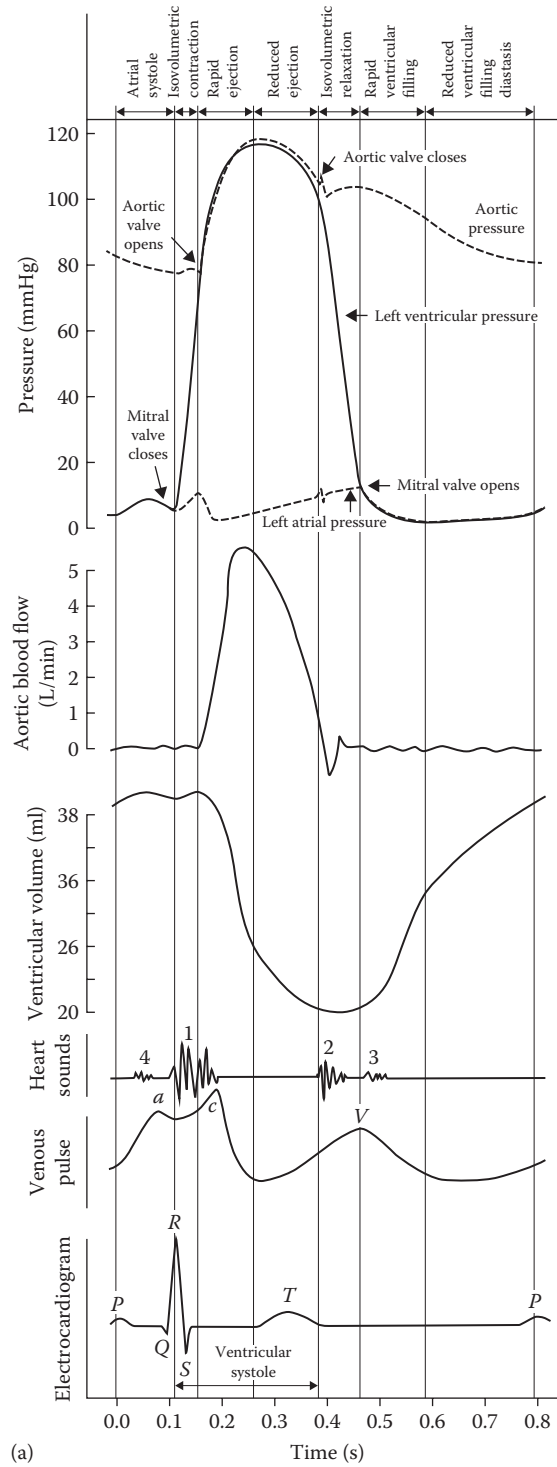


Figure F.38 Pulsatile flow representation: (a) human heart flow pulsation and pressure form.

(Continued)

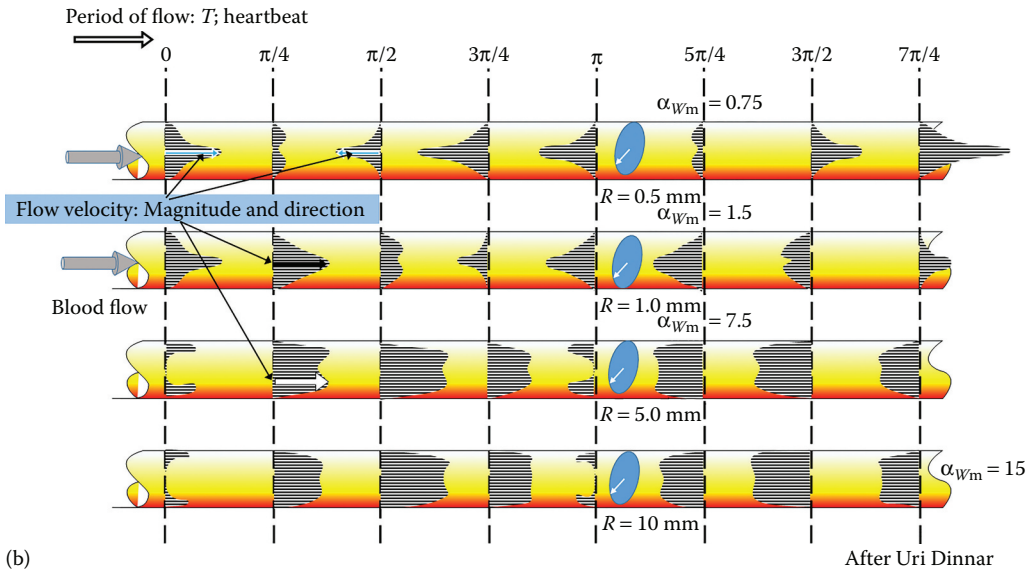


Figure F.38 (Continued) Pulsatile flow representation: (b) pulsatile vascular flow velocity profile (relative magnitude) for non-Newtonian liquid, based on the work of Uri Dinnar (1939–2013). $\alpha^2 = \omega_n R^2/\nu$, for a pump frequency ν , in a tube diameter R with the n th harmonic flow velocity $\omega_n = 2\pi\nu_n$. This is generally valid in blood vessels ranging from $R = 100 \mu\text{m}$ to $R = 15 \text{ mm}$. (From Dinnar, U., *Cardiovascular Fluid Dynamics*, CRC Press, Boca Raton, FL, 1981.)

Fludeoxyglucose (FDG)

[atomic, biomedical, chemical, imaging, nuclear, solid-state] A **RADIOPHARMACEUTICAL** used in positron emission TOMOGRAPHY fluoride (^{18}F) is the active component in FDG, **RADIONUCLIDE** half-life, and inherent ENERGY ^{18}F : 110 min, $E_{^{18}\text{F}} = 0.64 \text{ MeV}$, which decays as $^{18}\text{F} \rightarrow ^0_{+1}\text{e} + ^{18}_8\text{O}$, where oxygen is released, $^{18}_8\text{O}$. The fluoride is incorporated in biological process and decays involving the annihilation process of the positron ($^0_{+1}\text{e}$) or BETA PARTICLE, producing subsequent gamma RADIATION that can be captured to locate the chemical events and hence map the physiological ACTIVITY as a function of volume location in the biological medium. Specifically, FDG acts as a GLUCOSE equivalent hence illustrating the metabolic rate, which can specifically indicate cancer as well as brain activity.

Fluence ($\bar{\Psi}(r, \theta, \phi)$)

[astrophysics/astronomy, biomedical, electromagnetism, energy, optics, thermodynamics] Exposure of PHOTON or MECHANICAL ENERGY to a surface, vector expression of radiant exposure. The light energy per unit area is expressed by the average POYNTING VECTOR ($\vec{S} = (1/\mu_0)(\vec{E} \times \vec{B}) = \vec{E} \times \vec{H} = (\sqrt{\epsilon_0\mu_0}/4\pi)(\vec{E} \times \vec{B})$, $c = \sqrt{\epsilon_0\mu_0}$ the speed of light): $\bar{\Psi}(r, \theta, \phi) = \vec{S} \cdot \vec{n} = ((\vec{E} \times \vec{B})/\mu)/\mu$ (μ the DIELECTRIC permeability of the medium, ϵ the permittivity of the medium). In general, the energy is the integral of the photon or ionizing particle FLUX over the time of exposure in a specific location. Alternatively, the particle flux can be counted by detectors. The fluence concept is based on the work by SIR FRANZ ARTHUR FRIEDRICH SCHUSTER (1851–1934) from Germany in 1905 and KARL SCHWARZSCHILD (1873–1916) from Germany in 1906. The exposure time can be a limited duration PARTICLE stream, ionizing ELECTROMAGNETIC RADIATION or laser pulse (e.g., alpha, electron next to gamma, ULTRAVIOLET, visible, and INFRARED, respectively). The units for fluence are $[\text{J}/\text{m}^2]$, alternatively for particle stream $[\text{m}^{-2}]$. The fluence in a location determines the thermal effects that will be achieved over a period of exposure to electromagnetic radiation, in particular, exposure to laser light (see Figure F.39).

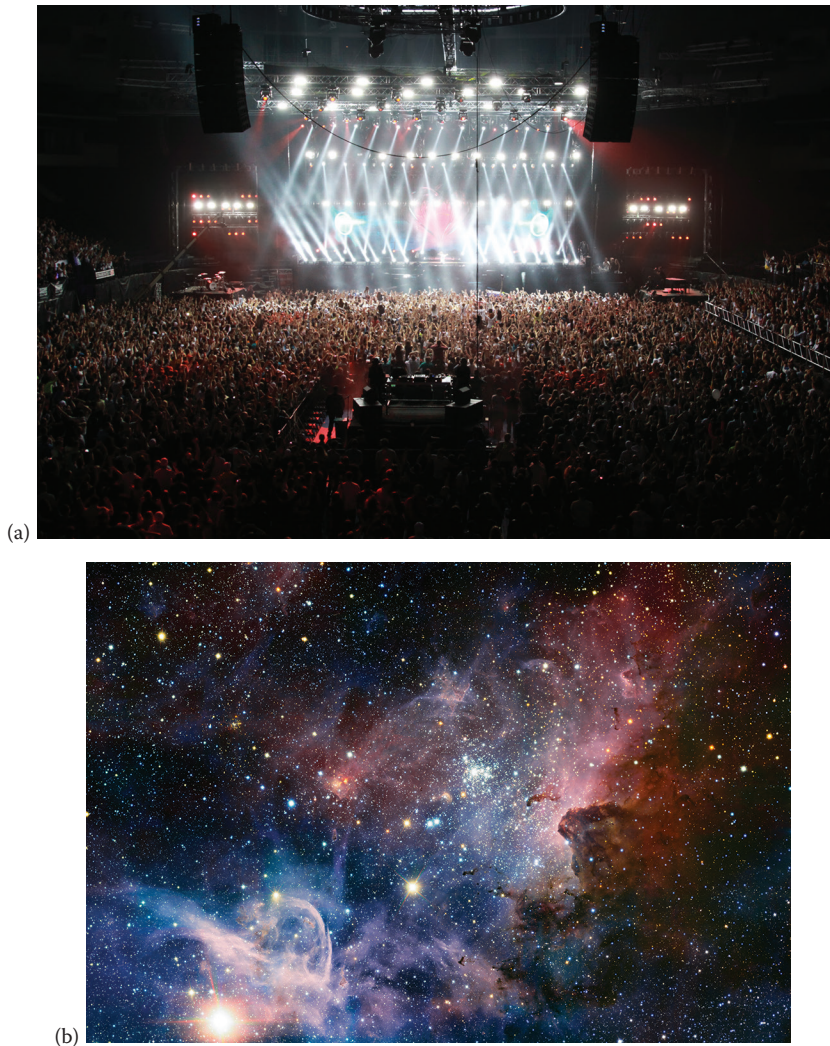


Figure F.39 (a) The fluence on the podium and the audience during a rock concert. (b) The fluence from the distant Carina Nebula, scattered by space debris, captured by the Hubble telescope. (Courtesy of ESO/T. Preibisch.)

Fluence rate ($\Phi(r, \theta, \phi, t)$)

[biomedical, chemical, electromagnetism, energy, optics, thermodynamics] When presented as radiant ENERGY fluence rate, it represents the intensity equivalent for ELECTROMAGNETIC RADIATION. Intensity of electromagnetic radiation is ill-defined since intensity by definition is the AMPLITUDE of a phenomenon squared and electromagnetic radiation has two paired phenomena: (1) alternating electric field strength and direction and (2) alternating MAGNETIC FIELD strength and direction. The fluence rate $\Phi(\vec{r})$ is the radiance $L(\vec{r}, \vec{s})$ (also described as irradiance) in location $\vec{r}$ with direction $\vec{s}$ integrated over SOLID ANGLE (4π): $\Phi(\vec{r}) = \int_{4\pi} L(\vec{r}, \vec{s}) d\omega$. The fluence rate identifies the RADIATION power received, transferred, or emitted from the surface of a volume, a (small) sphere of medium with finite but small dimensions at the location $\vec{r}$. The concept of fluence rate was introduced by the biologist from the United States, Claud Stan Rupert (1919–) in 1974 for the description of influence of light on the repair mechanism of DNA. The units for fluence rate are (W/m^2). Fluence rate and irradiance have the same units but have a fundamentally different meaning in light exposure. Irradiance describes the linear impact of electromagnetic radiation on a plane surface,

not on a spherical surface. This term is commonly used to describe the light distribution inside a turbid medium. The difference with irradiance is in fact energy FLUX crossing the surface of a volume of medium, which is only equal to the fluence rate when the incident flux is orthogonal to the surface. The location-specific generation of heat in a medium under irradiation is the local absorption coefficient multiplied by the fluence rate as a function of location. The chemical effects of light interaction are a direct result of the fluence rate. For instance, in PHOTOSYNTHESIS, or alternatively in photodynamics therapy, the fluence rate determines the efficacy for the process, provided through dose–response curves. Photodynamics therapy is the treatment of cancer by excitation of singlet oxygen to form a reactive component that initiates CELL death, primarily through the disintegration of the local vasculature. Photosynthesis is the conversion of light energy in a chemical reaction that converts carbon dioxide into oxygen and carbon waste by-product. Also found as $E_{p,0}$. It is also referred to as SCALAR radiance (*also see* EQUATION OF RADIATIVE TRANSFER).

F

Fluid

[biomedical, chemical, fluid dynamics] State of a medium that is not solid, while GAS and LIQUID phase are fluids. The atoms, molecules, and ions, respectively, are allowed to freely move about with respect to each other. In a liquid the atoms or molecules do maintain a relatively fixed DISTANCE to each other, whereas in a gas the atoms and molecules have no particular correlation in distance. A gas will fill a volume to all the boundaries, while a liquid will only conform to the five walls of a container. Fluids can be ideal or nonideal (not adhering to the standard laws and continuity equations), for instance, the case of the IDEAL GAS. Furthermore, fluids can be compressible or incompressible, which affects the theoretical treatise of the problem in significant ways. Frequently, for simplicity, a fluid is considered inviscid (absence of VISCOSITY) and incompressible. In case the FLOW itself changes the ENERGY and entropy content, the process can become rather complex from a computational point, hence adiabatic flow is preferred from a first-order point of view. From a dynamic perspective fluids can be classified as Newtonian or non-Newtonian. The NON-NEWTONIAN FLUIDS can be subclassified as being independent of time and shear and those who are dependent. The various formats of shear rate of flow are dilatant fluid (shear thickening), Newtonian, pseudoplastic (shear thinning), and Bingham fluid. A special phenomenon of fluid flow is described by the FÄHRÆUS–LINDQVIST EFFECT, which applies for instance to BLOOD flow as a function of tube diameter. One parameter of particular interest for fluids is the viscosity. Various laws and DIMENSIONLESS NUMBERS are involved in defining the behavior of fluids. In particular, fluid flow creates boundary layers at the interfaces with other media, moving or stagnant walls. One phenomenon that exemplifies the BOUNDARY LAYER is the collection of a layer of dust on the blade of a fan PROPELLER, or algae growing on the blade of the propeller of a ship. Some laws of interests include Bernoulli's law, Navier–Stokes, and Poiseuille profile. For gases the Boyle–Gay–Lussac law is important for the description of equilibrium conditions, with modifications such as the Van der Waals equation. During gas exchange with liquids, the VAN'T HOFF EQUATION comes into play to describe the partial pressure of dissolved gasses in a liquid. One force of particular interest with respect to flow is the CORIOLIS FORCE. Another phenomenon that comes into question with regard to flow is TURBULENCE and vorticity; with particular attention to the Von Kármán vortices (e.g., VON KÁRMÁN VORTEX STREET) in various flow situations. Flow can be laminar or turbulent, with a special case for COUETTE FLOW. Some of the dimensionless numbers are ARCHIMEDES number, Atwood number, Bagnold number, Bejan number, Bond number, Brinkman number, Brownell–Katz number, CAPILLARY number, Colburn J factors, Darcy friction factor, DEAN NUMBER, Deborah number, Eötvös number, Ericksen number, Euler number, Fanning friction factor, Froude number, Galilei number, Görtler number, Graetz number, Grashof number, Hagen number, hydraulic gradient, Iribarren number, Karlovitz number, Keulegan–Carpenter number, Knudsen number, Kutateladze number, Laplace number, LIFT COEFFICIENT, (Love numbers), Lundquist number, MACH NUMBER, NUSSELT NUMBER, Ohnesorge number, Péclet number, pipeline parameter, POWER NUMBER, Prandtl number, REYNOLDS NUMBER, Richardson number, Roshko number, Rossby number, Rouse number, Schmidt number, SHAPE FACTOR, (Sherwood number), Sommerfeld number, Stanton number, Stokes number, Strouhal number, Taylor number, Ursell number, Vadasz number, VAN'T HOFF FACTOR, VISCOSITY (static, kinetic, various conditions), Weber number, Weissenberg number, and WOMERSLEY NUMBER. In biology, specific definitions are applied to fluids with respect to their role and anatomical location. Interstitial fluids in biological entities fill the space surrounding cells as well as organs, while extracellular fluid is part of this fluid system and only

involves the immediate perimeter of the CELL. The cell itself is filled with intercellular fluid. The chemical differences between these fluids provide specific chemical, mechanical, nutritional, and transportation functions. The fluid balance for a biological system, fluid intake, and fluid excretion form the HOMEOSTASIS. Blood flows, while sweat, urine, and amniotic fluid have a discrete migratory pattern. Sweat, for instance, plays a critical role in the thermal regulation of the body for many animals; a thermodynamic mechanism. Synovial fluid provides LUBRICATION in JOINTS. Oils are a fluid, serving a role in lubrication, as is grease. Grease is a non-NEWTONIAN FLUID.

Fluid dynamics

[fluid dynamics, general] Field in ENGINEERING and PHYSICS that concerns itself with the dynamic aspects of phases, ENERGY states, transitions, motions, and parameters of fluids. Fluid dynamics also is involved in the description of flight as well as FLOW in canals, tubes, and waves coming on shore at the beach (see [Figure F.40](#)).



Figure F.40 Fluid dynamic aspect of mixing in a blender.

Fluidization

[fluid dynamics, solid-state] Transition process for a colloidal/particulate aggregate from static solid conditions to a fluidic state under dynamic MOTION. The medium can also be considered a non-NEWTONIAN FLUID, such as a concrete or cement mix, next to a straightforward PARTICLE aggregate such as coffee grinds being ejected from the espresso grinder, or gumballs flowing from a candy machine, or the infamous quicksand next to the mechanism of operation for the hourglass (see [Figure F.41](#)).



(a)

Figure F.41 Visualization of fluidization: (a) ground coffee flowing from dispensing unit.

(Continued)



Figure F.41 (Continued) Visualization of fluidization: (b) dump truck unloading sand and (c) flow of wheat grain during harvest. (Courtesy of Charles Knowles.)

Fluidization number

[fluid dynamics, solid-state] Ratio between the voids in a bed of two powders, or a powder and a FLUID, that indicates a transition during MOTION from powder mixture to separate powders, expressed as $N_{fl} = \rho_d^3 d_p^4 g^2 / \eta_{visc}^2 E_Y$, where ρ_d is the density of the solids in the fluid motion (fluidized), d_p the particulate diameter, η_{visc} the VISCOSITY of the fluid (respectively, complementary PARTICLE) surrounding the particles, E_Y the elastic modulus, and g the GRAVITATIONAL ACCELERATION, which needs to be corrected for rotational effects as $g_{app} = \sqrt{(g^2 + \omega^4 r^2)}$ (r the particulate radius; ω the CIRCULATION rotational ANGULAR VELOCITY).

Fluorescence

[atomic, general, nuclear, optics] Re-emission of light from a substance when irradiated with light at a different wavelength, specifically a longer (i.e., lower ENERGY) wavelength. The amount of photons that are emitted from a single volume of the specimen seeded with fluorochrome material can be quantified as described by the number of photons emitted per fluorochrome n_a as $n_a \cong (p_0^2 \delta / \tau_p f_p^2) [\pi (NA)^2 / bc \lambda]$. The parameters of this formula are as follows, p_0 is the average excitation light power (preferably delivered by narrow laser line width matching the excitation conditions), f_p is the repetition rate of the delivery of light, the pulse width of the light

delivery is given by τ_p , λ is the excitation wavelength of the light delivered by the laser, NA is the NUMERICAL APERTURE, $h = 6.6260755 \times 10^{-34}$ Js the Planck's constant, with c the speed of light and the photon CROSS SECTION is represented by δ . When measuring the fluence emitted as a function of ANGLE and location the origin of the volume with the highest emission can in theory be derived. The fluorescent emission as a function of location can provide details about the distribution of certain molecular concentrations (see Figure F.42).



Figure F.42 Fluorescence: (a) fluorescent body art. (Courtesy of Beo Beyond, www.beobeyond.com.) (b) Fluorescent light bulb.

Fluorescence resonance energy transfer (FRET)

[biomedical, chemical, imaging] Atomic excitation process, particularly important for the localization of nucleic acids, specifically with respect to the identification and localization of genetic encoding by means of labeled proteins on a nanometer scale (e.g., within the DNA molecule). The RESONANCE ENERGY transfer takes place between two light-sensitive molecules in living cells. The energy transfer process by means of DIPOLE-DIPOLE INTERACTION avoids chemical interaction per se. FRET is used to map molecular configurations, molecular transfer phases (stages), enzyme ACTIVITY, as well as DNA hybridization (active process traced in time) and the DYNAMICS of membranes. FRET transfer is a specific form of FÖRSTER RESONANCE ENERGY TRANSFER, as described by the scientist from Germany THEODOR FÖRSTER (1910–1974) in 1946.

Flux

[atomic, electronics, fluid dynamics, general, nuclear] Migration of energetic units through a fixed surface. The flux describes the line density of electric and/or MAGNETIC FIELD lines (the line density is a direct representation of the MAGNITUDE of the field strength), particulate transport, PHOTON fluence, or generally the “FLOW” component perpendicular to a surface (generally captured by the “dot” product) such as FLUID flow. In generalized terms, the flux of a vector field is described by the integral of the field distribution over the surface of impact. In ELECTROMAGNETIC THEORY, GAUSS’S LAW defines the electric field flux through a closed surface ($\Phi_e = \oint \vec{E} \cdot d\vec{A}$), and the FARADAY LAW yields the magnetic flux through a bounded surface ($\Phi_m = \int_{\text{surface}} \vec{B} \cdot d\vec{A}$).

FM transmissions

[general] Frequency modulation, primarily pertaining to ELECTROMAGNETIC RADIATION. FM RADIO is the most popular form of wireless transfer of information, and can be applied in STEREO, compared to AM and long-wave radio that is single channel and low bandwidth.

f-number

[optics] Number representing the **ANGLE** subtended by the entrance opening at the axis of the object. For a **CAMERA LENS**, this is defined by the ratio of the focal length to the pupil diameter. A camera lens with adjustable **APERTURE** will have the *f*-number indicated on a ring of the lens that can be rotated for adjustment. An *f*-number smaller than 1 is considered to enhance brightness. It is also called *f*-stop (*also see* **NUMERICAL APERTURE**) (see [Figure F.43](#)).



Figure F.43 f-stop adjustment ring on telephoto lens of a camera.

Focal length (f)

[electromagnetism, general, imaging] The DISTANCE from the focusing instrument where the concentration of field lines is the greatest; in OPTICS the combined ELECTROMAGNETIC FIELD density. The focal length is the distance of the FOCAL POINT with respect to the focusing device (optical lens; magnetic lens) on the optical axis, which is the cylindrical axis of symmetry. In an ELECTRON MICROSCOPE, the electron FLUX density will be greatest in the focal point provided by magnetic steering units (magnetic coil lenses; used both in TRANSMISSION ELECTRON MICROSCOPE and REFLECTION electron microscope/scanning electron microscope). An object located in the focal point can be analyzed with the highest RESOLUTION. In addition, curved reflective surfaces also provide a focusing action, with associated focal length, specifically the use of parabolic mirrors in head lights of automobiles, and dish antennas for television and galactic RADIO (MICROWAVE emissions from atomic transactions) SIGNAL collection. Multiple lens systems, such as those in cameras and projectors provide a focusing action that allows for adjusting the focal length in order to form an IMAGE on the film at fixed distance from the LENS (image distance: d_i) from objects at selective distance (the object distance: d_o). The focal length (f) is correlated to the image distance and the object distance as $1/f = (1/d_i) + (1/d_o)$, where the image distance for a virtual image has a negative value; hence the focal length can become negative, specifically for a DIVERGING LENS. For a diverging optical lens, generally, the center (at the optical axis) is thinner than toward the edges. However, an object placed in front of a converging lens at a distance smaller than the focal length will also form a virtual image (i.e., cannot be projected) (see Figure F.44).

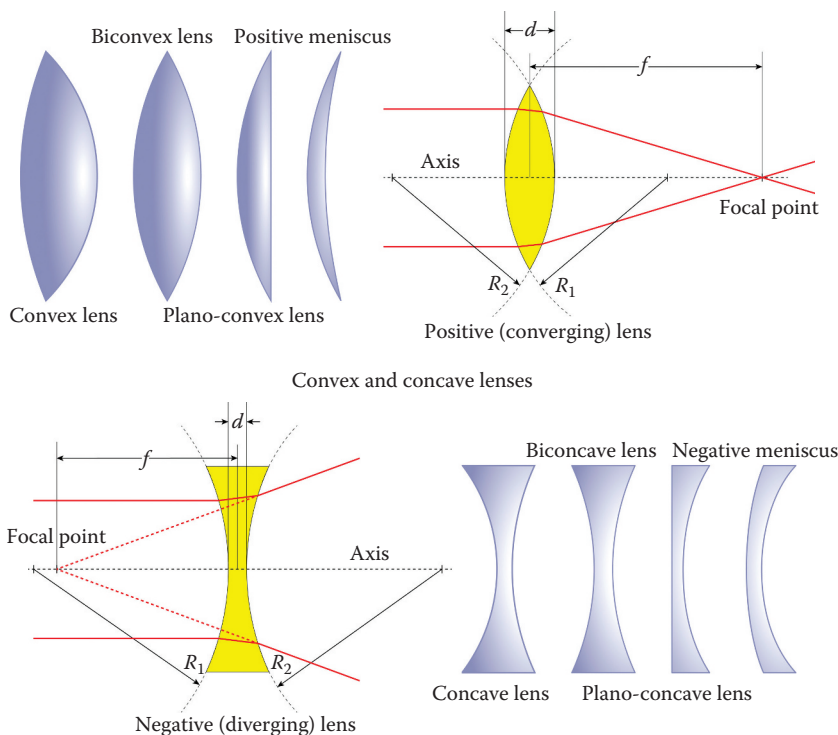


Figure F.44 Focal length.

Focal plane

[general, optics] Plane in which the **IMAGE** is formed from infinite **DISTANCE**, either on the optical axis or off the optical axis. The image formation for an object (or location on an object with finite dimensions) that is not on the optical axis yields a convergence of rays that does not coincide with the optical axis. The focal plane for a projector is generally adjusted to coincide with the location of the screen, or **WALL** for in-focus viewing.

Focal point

[general] The infinitely small point on the optical axis of a device where all the incident rays parallel with the optical axis converge. The focal point is located at the focal **DISTANCE** from the optical device (e.g., optical lens, **MAGNET**, **MIRROR**). An infinitely small **LIGHT SOURCE** placed in the focal point of a perfect **LENS** system will form a ray that is parallel to the optical axis leading to infinity. Any object of finite size placed in the focal point constitutes the **FOCAL PLANE** with respect to that object for the imaging device. The fact that the focal point of the instrumentation used for focusing does not coincide with the focal plane when moving away from the optical axis will result in distortions in the **IMAGE** (i.e., **SPHERICAL ABERRATION**). Similarly, the focal point (“in focus”) for a perfectly configured lens (system) at a single wavelength (without spherical aberration) can have differences in index of **REFRACTION** for various wavelengths and hence resulting in different focal points for different wavelengths. The disparity in wavelength focusing (**DISPERSION**) is referred to a chromatic aberration, yielding **COLOR** distortions in the image formation. When an image that is formed from an object that is not on the optical axis is distorted, it is referred to as “coma.” A particular form of coma is **ASTIGMATISM**, in which an image is contorted by nonradial symmetry in the optical focal length for the lens system (*also see* **THIN LENS** AND **THICK LENS** and **LENS EQUATION**).

Forbidden transitions

[atomic, nuclear] Both on an atomic electron level as well as with respect to energetic migrations of nuclides of an **ATOM** there are specific **ENERGY** constraints that provide **ALLOWED TRANSITIONS** as well as define forbidden transitions. The primary constraint in subatomic **PARTICLE** and elementary particle energy transitions is associated with the **SPIN** (and respective **PRECESSION**) of the rotating particle and particularly with respect to other energetic particles of the same class. An allowed transition obeys the selection rules that are primarily associated with the solutions to the **SCHRÖDINGER EQUATION**, the complement are the forbidden states. Forbidden transitions thus violate the selection rules. One particular exclusion rule is the fact that two particles in the same system with the same energy cannot have identical spin. Another example of an allowed transition is the change in angular momentum limited by unit change in the orbital angular momentum **QUANTUM NUMBER** (*also see* **PAULI EXCLUSION PRINCIPLE** and **SELECTION RULES**).

Force (F)

[general, fluid dynamics, mechanics, nuclear, thermodynamics] A vector of influence in the direction of the acceleration (a) of a body with mass m . Force is defined by **NEWTON'S SECOND LAW**, where the sum of the forces equals the mass of the body times the acceleration: $\vec{F} = \Sigma \vec{F}_i = m\vec{a}$, the push or pull which tends to initiate **MOTION** to a body at rest, the product of the mass of the body (m), and its acceleration ($\vec{a}$ with both a **MAGNITUDE** and a direction). Also, the influence applied on a body to increase or diminish the speed or change the direction of a body already in motion. Other definitions are used in specific external conditions, which still entail **COMPLIANCE** with mass multiplied by acceleration. In **ELECTRICITY** and **MAGNETISM**, the Lorentz force law is defined as $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$, with q the **ELECTRIC CHARGE** of the body in motion

in an electric field $\vec{E}$, while traveling at velocity $\vec{v}$ and when exposed to an additional MAGNETIC FIELD $\vec{B}$. Conservative force is defined by the fact that the work performed by the force is independent of the path (s) over which the work is performed. The conservative force is identified by the change in potential ENERGY (PE), defined in magnitude as $F = dPE(s)/ds$ (also see **FOUR FORCES**).

Forced oscillation

[energy, fluid dynamics, general, mechanics, thermodynamics] Periodic perturbation from equilibrium as the result of external influences. A forced oscillation of a mass m , with inherent resonant functionality obeys the harmonic OSCILLATOR equation for displacement z as a function of time t under the influence of applied force (F ; fluctuating with ANGULAR FREQUENCY ω) expressed as $m(d^2z/dt^2) + b(dz/dt) + kz = F \sin \omega t$, where k is the spring constant, b the DAMPING. Note that the undamped, unforced VIBRATION will have a NATURAL FREQUENCY $\omega_0 = \sqrt{(k/m)}$. The forced oscillation will have maximum AMPLITUDE at the resonant frequency $\omega_R = \sqrt{((k/m) - (b^2/2m^2))}$. An electrical OSCILLATION can be provided by the circuit construction with CAPACITOR, INDUCTOR, and RESISTOR; for instance, in a RADIO STATION, emitting ELECTROMAGNETIC RADIATION. One particular forced OSCILLATION is the MICROWAVE energy-induced molecular vibration of water molecules in a MICROWAVE OVEN, under the ELECTROMAGNETIC FIELD resulting from a magnetron. On a swing the forced oscillation is fueled by the mechanical MOTION of swinging of the legs while leaning and changing the location of the CENTER OF GRAVITY on a periodic basis. An army platoon will need to pass a bridge out-of formation, to reduce the chances of generating a RESONANCE FREQUENCY that may actually break the structural integrity of the bridge. An example of a mechanical vibration is the combination of a spring, a damping pod, and the equivalent of a mechanical inductor, or a true electrical inductor; for example, Woofer, VOICE COIL; see MASS-SPRING SYSTEM (also see OSCILLATION and DRIVEN DAMPED HARMONIC OSCILLATOR) (see Figure F.45).



Figure F.45 Snapshot of forced oscillation: second string from top on guitar after being “plucked.”

Forced vibration

[dynamics, fluid dynamics, general, mechanics] In contrast to self-excited vibrations there is an external force applying the oscillatory ENERGY fluctuations. The OSCILLATION frequency is directly linked to the rate of change of the driving force.

Forced vortex

[engineering, fluid dynamics] Rotational MOTION of a medium or a container filled with a LIQUID where the rotational velocity is a function of radius due to the internal VISCOSITY and rotational momentum (more mass on the outer limits than toward the center). A bottle of liquid placed on a rotating table (turntable) will produce an exemplary forced vortex. FLUID FLOW along a rotating device also induces a forced vortex. The pressure for a GAS flow in a forced vortex adheres to $P_o/P_i = \{1 + ((K_r \omega R_i)^2 / 2c_p T_i)[(R_o/R_i)^2 - 1]\}^{\gamma_p/\gamma_p - 1}$, where K_r is the core swirl (ratio of transfer of rotation of the core with radius R_i and ANGULAR VELOCITY ω to the surrounding gas; $0 \leq K_r \leq 1$), in a volume with radius R_o (also, for the pressure $[P]$, the inner P_i and outer $[P_o]$ values are the ones affected), T_i the internal temperature, γ_p the pressure correction factor, and c_p the SPECIFIC HEAT at constant pressure. A forced vortex will also be found in the vicinity of a PROPELLER, both in liquid or in gas (*also see* TORSION WAVE *and* TORSIONAL OSCILLATIONS) (see [Figure F.46](#)).



Figure F.46 Forced vortex resulting from stirring in chocolate syrup into milk.

Förster, Theodor (1910–1974)

[biomedical, chemical, imaging] Scientist from Germany. Theodor Förster provided significant contributions in the experimental investigations and theoretical description of the ATOMIC ENERGY transfer between nonradiative states through dipole–dipole coupling, that result in fluorescent DECAY with inherent details about the ENERGY configuration on a molecular level. The emitted RADIATION is a direct function of the molecular spacing, with the energy transfer (and hence to emission wavelength; spectral line) inversely

proportional to the DISTANCE between the donor CHROMOPHORE and acceptor chromophore to the sixth power. This is also of influence in the Franck–Condon effect (see [Figure F.47](#)).



Figure F.47 Theodor Förster (1910–1974). (Courtesy of the University of Düsseldorf, Düsseldorf, Germany.)

Förster resonance energy transfer

[biomedical, chemical, imaging] Nonradiative dipole–dipole CHROMOPHORE ENERGY transfer as described by scientist THEODOR FÖRSTER (1910–1974) from Germany. The detection of the fluorescent spectrum and fluence provides details about the inter-dipole spacing and energy configuration of the constituents. When the two light sensitive chromophores are providing fluorescent signaling. The process is more generally referred to as FLUORESCENCE RESONANCE ENERGY transfer (*see* FLUORESCENCE RESONANCE ENERGY TRANSFER [FRET]).

Fosbury flop

[general, mechanics] The curved backward roll over a high bar for jumpers. The curved body actually places the CENTER OF GRAVITY below the bar, hence reducing the required ENERGY to reach a higher jump level (see [Figure F.48](#)).



Figure F.48 Fosbury flop.

Foucault, Jean Bernard Léon (1819–1868)

[general, optics] Physicist from France. In the year 1850, Foucault derived the speed of light in water and compared it to the established speed of light in AIR derived by ARMAND HIPPOLYTE LOUIS FIZEAU (1819–1896). Foucault did a similar MEASUREMENT as Fizeau, but with a rotating MIRROR. He measured the returning ANGLE of the reflected light over a DISTANCE of 18 m to the mirror and back, due to the rotation of the mirror, and concluded that the speed of light had to be 2.99796×10^8 m/s in air, in the year 1850, within 10^{-3} % of the accepted standard in VACUUM: 2.99792458×10^8 m/s. Foucault was also the first person to conceive and construct a GYROSCOPE (see [Figure F.49](#)).



Figure F.49 Jean Bernard Léon Foucault (1819–1868).

Foucault current

[energy, general, electromagnetism] see **EDDY CURRENT**. The Foucault name remains attached to this phenomenon due to the theoretical contributions provided by JEAN BERNARD LEON FOUCAULT (1819–1868).

Foucault's pendulum

[mechanics, geophysics] Device designed to visually illustrate the rotation of the EARTH, introduced in 1851. A pointed, heavy ($m \sim 28$ kg) object suspended from an excessively long cable (67 m) ("bob") is moving in pendulum MOTION with the sharp point indicating the path with respect to a geometric map outline directly below it, angular outline. The PENDULUM, as originally placed in Paris, France, will perform a full circular crossing over a period of 32.7 h, rotating the direction of swing in 11° increments, clockwise, per hour. These experiments were performed by JEAN BERNARD LÉON FOUCAULT (1819–1868). The direction in which the pendulum swings changes in clockwise rotation from the first linear path, and continues to make an ANGLE with the initial path on each swing, ever increasing. The forces acting on the swinging bob are following

Coriolis forces, in longitudinal and latitudinal directions, respectively, $F_{C,x} = 2m\omega_e(dy/dt)\sin\varphi$, where ω_e represents the angular velocity for the rotation of the Earth; note that the CORIOLIS FORCE is a function of the LATITUDE ANGLE φ ; $F_{C,y} = -2m\omega_e(dx/dt)\sin\varphi$. The equation of motion expressed in complex notation $\tilde{z} = x + iy$ yields $(d^2\tilde{z}/dt^2) + 2i\omega_e(d\tilde{z}/dt)\sin\varphi + \theta^2\tilde{z}$, where θ represents the rotation of swing direction. The solutions are in first-order approximation: $\tilde{z} = e^{-i\omega_e\sin\varphi t} (C_1e^{i\theta t} + C_2e^{-i\theta t})$ (also see CORIOLIS FORCE) (see Figure F.50).



Figure F.50 Foucault's pendulum.

Four forces

[general] Four forces of nature GRAVITY, weak nuclear, (the prior two are part of general ELECTROWEAK FORCE), electromagnetic, and strong nuclear.

Fourier, Jean Baptiste Joseph, Baron (1768–1830)

[acoustics, computational, imaging, optics, theoretical] French mathematician and scientist. Joseph Fourier is best known for his computational approach to complex function analysis, specifically the **FOURIER TRANSFORM** (also see **JOSEPH, JEAN BAPTISTE FOURIER**) (see [Figure F.51](#)).



Figure F.51 Jean Baptiste Joseph Fourier (1768–1830).

Fourier analysis

[atomic, computational] Mathematical analysis introduced in 1822 by the French mathematician **BARON JEAN BAPTISTE JOSEPH FOURIER** (1768–1830) using the decomposition of functions in a series of trigonometric functions: $F(\omega) = \sum_{n=0}^{\infty} (A_n \cos(n\omega_0 t + \alpha_n) + B_n \sin(n\omega_0 t + \alpha_n))$, where t is time when operating in the frequency domain (time and frequency are equivalent with respect to the alternative: location), α_n is the **PHASE** shift, C_n constant for term n , and ω_0 the **FUNDAMENTAL FREQUENCY** for the phenomenon. In case the phenomenon is not harmonic, the series is not necessarily an arithmetic sequence: $F(\omega) = \sum_{n=0}^{\infty} C_n \cos(\omega_n t + \alpha_n)$, where the coefficients are derived from the original function $f(t)$ (see **FOURIER TRANSFORM**).

Fourier conduction law

[thermodynamics] the rate of heat **FLOW** (Q/t , where Q is the heat and t the time) as a result of a temperature gradient ($\Delta T/d$, where ΔT represents the temperature gradient, specifically perpendicular to the surface: $\partial T / \partial n$, and d the length) across an area (A) expressed as $\dot{Q} = Q/t = dQ/dt = k_T A (\Delta T/d)$, where k_T is the **THERMAL CONDUCTIVITY** of the medium.

Fourier number ($Fo = \kappa t / c_p L^2$)

[thermodynamics] Dimensionless number representing the ratio of the heat conduction per unit time to the rate of thermal storage. The Fourier number mainly applied to solids, with L the characteristic length of the solid, t is time, c_p the **SPECIFIC HEAT CAPACITY**, ρ the **DENSITY** of the solid, and κ the **THERMAL CONDUCTIVITY**. The number is used, for instance, in an alternating or transient conductive **COOLING** and **HEATING** situation, converting the thermal **CONDUCTION** equation in a nondimensional expression. The Fourier number provides a dimensionless time for the period over which a temperature change will occur. Considering that the unsteady **DIFFUSION EQUATION** is mathematically equivalent to the unsteady

conduction equation, the same principles can be used to solve mass transfer situations. For mass transfer the partial differential and continuity equations will have definitions and variables that are different than for HEAT TRANSFER, such as DIFFUSION versus THERMAL CONDUCTIVITY and so on.

Fourier number, mass transfer ($Fo_m = D_{AB}t/L^2$)

[computational, fluid dynamics, thermodynamics] Dimensionless number used in FLUID DYNAMICS. The ratio of the DIFFUSION rate of the constituents in SOLUTION to rate of permanent solution, with D_{AB} the diffusion rate, t time, and L the characteristic dimensional constant. Generally, the moisture content decrease with increasing MASS TRANSFER FOURIER NUMBER. The mass transfer Fourier number can be used as an indication of the drying time for a SOLUTE. This is the mass equivalent for the FOURIER NUMBER used in thermal diffusion. Generally, the mass transfer Fourier number provides a dimensionless time for the period over which a chemical diffusion will occur.

Fourier optics

[optics] Physical OPTICS branch within PHYSICS that analyzes the propagation of light through an optical system (e.g., diffractive media, turbid media) by means of linear system theory and harmonic analysis and deconvolution. The FOURIER ANALYSIS in IMAGE analysis uses a two-dimensional WAVE EQUATION. The two-dimensional (2D) wave equation forms a superposition of an array of harmonic functions with specific spatial frequencies and complex AMPLITUDES: $f(x, y) = \sum C_n \exp[-i2(\omega_{x,n}x + \omega_{y,n}y)]$, where $\omega_{x,n}$ and $\omega_{y,n}$ are the harmonic frequencies in the x and y directions, respectively. The amplitude (C_n) of each function (Fourier component), in complex form, is derived from the FOURIER TRANSFORM. The PLANE WAVE in 2D optics is the primary form of the projection of the three-dimensional wave process in image formation, providing an analysis of an arbitrary complexity profile. The 2D projects of the plane wave are referenced as wavefronts. Each respective WAVEFRONT progresses through space defined by the wavevector $\vec{k} = (k_x, k_y, k_z)$, $k = 2\pi/\lambda$, wavelength λ . The superposition principle applies to the wave expression as $f(x, y) = (2\pi)^{-2} \iint F(k_x, k_y) \exp[-i(k_x x + k_y y)] dk_x dk_y$, $F(k_x, k_y)$ the Fourier transform of the image function $f(x, y)$. In Fourier optics, a pinhole performs a physical Fourier transform of an image on the rays passing through the pinhole, projecting a diffraction pattern on a screen (see FOURIER TRANSFORM).

Fourier plane

[acoustics, computational, imaging] Dissection planes in the reconstruction process for three-dimensional IMAGE forming the correlation mechanism between the dissection lines and the planes as part of the “slice theorem.” This theorem states that the one-dimensional Fourier transform of the projection of an object is the same as the values of the two-dimensional Fourier transform of the object along a line drawn through the center of the two-dimensional Fourier transform. In general, the (Fourier) SLICE theorem relates the two-dimensional image to the one-dimensional projection, for instance, in computed TOMOGRAPHY (X-RAY) and ULTRASONIC IMAGING. In MRI, the process of the associated two-dimensional Fourier transform is transferred to what is known as “ k -SPACE.” The reconstruction of the image following backprojection ($f(\xi, \phi)$), with coordinates (ξ, ϕ, ρ) with $1/\rho$ being the FOURIER TRANSFORM for $1/r$ on each ANGLE in the respective Fourier plane is formulated as $g(r, \theta) = \int_0^\pi \int_{-\infty}^\infty \left\{ \int_{-\infty}^\infty f(\xi, \phi) e^{-i2\pi\rho\xi} d\xi \right\} |\rho| e^{i2\pi\rho r \cos(\theta-\phi)} d\rho d\phi$. The image reconstruction furthermore requires the interpolation between the one-dimensional Fourier transform derived from the source–detector scan to form a two-dimensional image in the Fourier plane. This is subsequently followed by the inverse Fourier transform in the Fourier plane to reconstruct the two-dimensional slice image. This process is an alternative to two other processes: backprojection and rho filter.

Fourier series

[atomic, computational, imaging, optics] Sum series of sinusoidal/cosine functions that are the transform of the original changing process, decomposed in processes of repetitive nature with multiples of the FUNDAMENTAL FREQUENCY of the original periodic phenomenon. The periodicity can be in the spatial domain or

in the frequency domain, specifically pertaining to the analysis of objects and images, next to data streams and optical regularities (e.g., DOUBLE-SLIT EXPERIMENT). A function of a phenomenon with periodicity L as a function of DISTANCE x^* (with the fundamental repetition pattern with wavelength $\lambda = 2L$) can be expanded in a Fourier series as $f(x^*) = \sum_{n=0}^{\infty} (A_n \cos(2\pi nx^*/L) + B_n \sin(2\pi nx^*/L)) = \sum_{n=-\infty}^{\infty} C_n e^{i2\pi nx^*/L}$ (all functions $e^{i2\pi nx^*/L}$ are orthogonal on the interval $x^* = -(x/L)$ to $x^* = +(x/L)$; orthogonality of functions is defined through $\int_{x_1}^{x_2} \varphi_m^* \varphi_n dx = 0$, φ_m^* , the complex conjugate switching the sign of all terms with i : $-/+$), where in most cases $A_n = 0$ due to the boundary conditions (general condition: $A_n = (1/\pi) \int f(x^*) \cos(nx^*) dx^*$), and B_n is the AMPLITUDES of the harmonics; $B_0 = (1/2\pi) \int_{-(L/2)}^{L/2} f(x^*) dx^*$ and $B_n = (1/\pi) \int_{-(L/2)}^{L/2} f(x^*) \sin(nx^*) dx^*$ with $n = 1$ representing the fundamental “wave” (see **FOURIER TRANSFORM**).

Fourier theorem

F

[nuclear] Computational behavior for several specific conditions and applications with respect to perturbations and involving more than one function: $f(x^*)$ and $g(x^*)$, with respective Fourier functions $F(v^*)$ and $G(v^*)$. Rules of transaction force functions and their respective Fourier transforms. Based on the fundamental **FOURIER TRANSFORM** principles, several inherent relations can be postulated for ease of use calculations. The theorems applied are for the following processes: addition, $f(x^*) + g(x^*) \rightarrow F(v^*) + G(v^*)$; AUTOCORRELATION, $\int_{-\infty}^{\infty} f(\chi) f(\chi + x^*) d\chi \rightarrow |F(v^*)|^2$; convolution, $f(x^*) * g(x^*) \rightarrow F(v^*) G(v^*)$; derivative, $df(x^*)/dx^* \rightarrow i2\pi v^* F(v^*)$; modulation, $f(x^*) \cos(2\pi f_0(x^*)) \rightarrow (1/2)F(v^* + f_0) + (1/2)F(v^* - f_0)$; shift, $f(x^* - x_0) \rightarrow F(v^*) e^{i2\pi v^* x_0}$; similarity, $f(c_1 x^*) \rightarrow |c_1|^{-1} F(v^*/c_1)$; and additionally, Rayleigh’s theorem, $\int_{-\infty}^{\infty} |f(x^*)|^2 dx^* = \int_{-\infty}^{\infty} |F(v^*)|^2 dv^*$.

Fourier transform

[astronomy/astrophysics, atomic, biomedical, computational, general, imaging, mechanics, optics, quantum] Probably the most commonly used **SIGNAL** transform applied to the analysis of signals and in **IMAGE** processing, introduced in 1822 by **BARON JEAN BAPTISTE JOSEPH FOURIER** (1768–1830). Joseph Fourier was investigating the propagation of heat and realized that the algorithm could significantly be simplified when the physical parameters were decomposed in terms of sets of trigonometry functions. The transform changes the spatial domain to the frequency domain, or respectively from the time domain to the frequency domain. The Fourier transform deconvolves a changing or periodic signal ($f(x^*)$) in an infinite number of harmonics with wavelength: λ (frequencies v : v_0 the fundamental and harmonics $2v_0, 3v_0, \dots$; note **WAVE** number $k = 2\pi/\lambda$), based on the one-dimensional formulation: $F(v^*) = FT\{f(x^*)\} = \alpha \int_{-\infty}^{\infty} f(x^*) e^{i\beta v^* x^*} dx^*$, where α and β are **NORMALIZATION** constant, both may frequently be found to be one, or a multiple of π (π). The parameters x^* and v^* should be dimensionally inverse; v^* indicative of the frequency variable. Most frequently the transform is from spatial location to spatial frequency. The Fourier function can be written as the **MAGNITUDE** ($|F(v^*)|$) multiplied by the complex **ANGLE** function with **PHASE** ($\angle F(v^*)$) as: $F(v^*) = |F(v^*)| e^{i\angle F(v^*)}$. When the reverse transform can also be applied the functions $F(v^*)$ and $f(x^*)$ are considered a Fourier pair ($f(x^*) = \alpha \int_{-\infty}^{\infty} F(v^*) e^{\pm i\beta x^* v^*} dv^*$). In two-dimensional format the transform is expressed in spatial frequencies (v^* and ξ^*) as a function of location (x^* and y^*) by the equation: $F(v^*, \xi^*) = \alpha' \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x^*, y^*) e^{-i2\pi(v^* x^* + \xi^* y^*)} dx^* dy^*$. Fourier transforms are convenient computational tools for complex situations such as for instance found in atomic crystals; ionic crystals; magnetic doublets; mechanical systems of point masses; electrostatic point charge distributions; optical configurations, in particular the use of narrow slits for spectral isolation, specifically applied to astronomy; and the **PARTICLE** distribution in **QUANTUM MECHANICS**. An example of the time **DECAY** $f(t) = e^{-t}$ ($t \geq 0$) yields the Fourier transform $F(v) = 1/(1 + i2\pi v)$. There are certain rules that apply to the Fourier function, defined by theorems. The theorems are addition, $f(x^*) + g(x^*) \rightarrow F(v^*) + G(v^*)$; AUTOCORRELATION, $\int_{-\infty}^{\infty} f(\chi) f(\chi + x^*) d\chi \rightarrow |F(v^*)|^2$; convolution, $f(x^*) * g(x^*) \rightarrow F(v^*) G(v^*)$; derivative, $df(x^*)/dx^* \rightarrow i2\pi v^* F(v^*)$; modulation, $f(x^*) \cos(2\pi f_0(x^*)) \rightarrow (1/2)F(v^* + f_0) + (1/2)F(v^* - f_0)$; shift, $f(x^* - x_0) \rightarrow F(v^*) e^{i2\pi v^* x_0}$; similarity, $f(c_1 x^*) \rightarrow |c_1|^{-1} F(v^*/c_1)$; and additionally, Rayleigh’s theorem, $\int_{-\infty}^{\infty} |f(x^*)|^2 dx^* = \int_{-\infty}^{\infty} |F(v^*)|^2 dv^*$. The Fourier transform of the Gaussian signal $f(x) = e^{-\pi x^2}$ has a **GAUSSIAN DISTRIBUTION** as well ($F(v') = e^{-\pi v'^2}$), which has

implications for the analysis of **ULTRASONIC IMAGING**, in particular considering nondiffracting waves. This concept applies to either location or time. A special application of the Fourier transform is the discrete Fourier transform. The discrete Fourier transform is applied when the function/phenomenon is a collective of events, expressed as $f(n)$, where $n=0,1,\dots,N$, such as the slats of a (endless) picket fence. The Fourier transform for this situation is defined as the repetition rate by means of $F(k^*) = \sum_{n=0}^{N-1} f(n)e^{-i(2\pi k^* n/N)t}$, where the number of samples in the frequency domain is the same as the number of points in time domain (N), with $k^* = 0,1,2,\dots,N-1$. Respectively with the inverse transform: $f(n) = (1/N)\sum_{k^*=1}^{N-1} F(k^*)e^{i(2\pi k^* n/N)t}$, $n = 0,1,2,\dots,N-1$. In the **SAMPLING** of the signal one specific condition applies, the sampling frequency of the signal needs to be minimally twice the highest frequency observed in the signal itself. This sampling constraint is referred to as Nyquist or Shannon theorem. This ensures that no critical information is lost by analyzing with at least half the shortest “wavelength”/pattern of the phenomenon. The half-wavelength criterion ensures capturing an equilibrium condition and an extreme; either a crest or a trough. The **INNER EAR**, based on its design, in fact performs a physical Fourier transform by means of the location-specific sensitivity to frequency of the cochlea (*also see* **FAST FOURIER TRANSFORM** and **LAPLACE TRANSFORM**) (see **Figure F.52**).

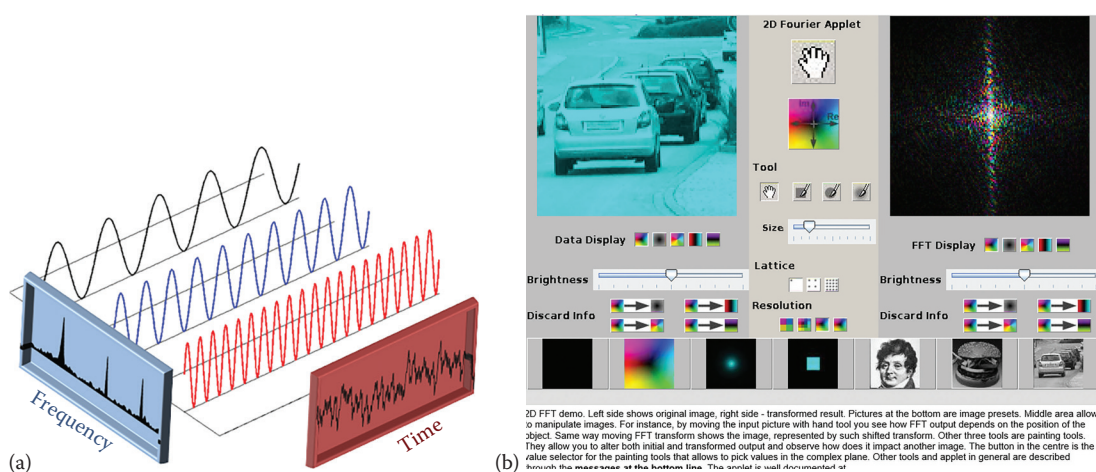


Figure F.52 (a) Outline of the process of the Fourier transform and (b) screenshot of a software program developed by UltraStudio (Fällanden, CH-8117, Switzerland; <http://ultrastudio.org>) that is designed to perform a spatial Fourier transform of the intensity frequency profile of an image.

Fovea

[biomedical, chemical, optics] Optical center point on the **RETINA** of the **EYE**, on the optical axis, consisting of **CONES** only. The fovea is the central part of the macula. The fovea is meant for high-resolution **COLOR** viewing, primarily under bright conditions; under dim lighting the **RODS** will provide imaging based on radiance only (grayscale). The cone density of the fovea is 6.5–7 million cones in a spot with a diameter of 1.5 mm. The macula also has rods mixed in, whereas the fovea consists solely of cones. In comparison, the entire lining of the retina is covered over better than 2π **SOLID ANGLE** with 120–130 million rods, respectively with highest density at 20° from the optical axis (*also see* **EYE**). Because of the high density of cones the **RESOLUTION** for an object placed in the **NEAR-POINT** of the eye provides an angular resolution of $0.3 \text{ arc min} = 0.0000872 \text{ rad}$ apart, resulting in a spatial resolution at the center wavelength 550 nm, applying a focal length of $2.2 \times 10^{-2} \text{ m}$

(the length of the HUMAN EYE), to an object placed in the near-point of the HUMAN EYE (~ 0.25 m; range varies per person and is dependent on AGE) yielding approximately $88.65 \mu\text{m}$ on average (see EYE and RETINA) (see Figure F.53).

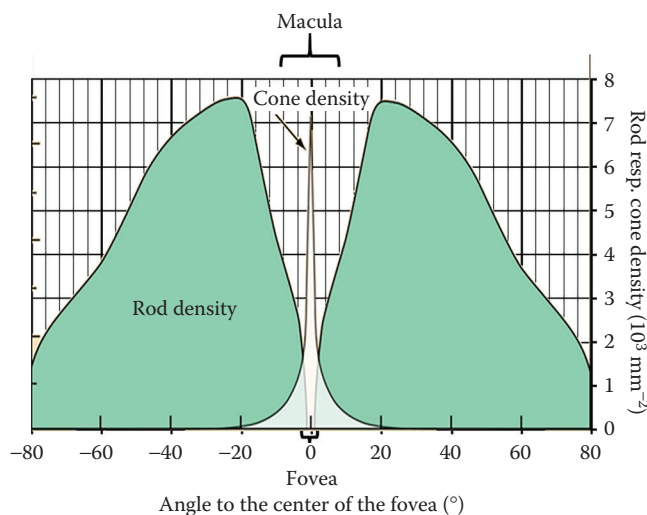


Figure F.53 Graphical representation of the location and size of the fovea in a cross-sectional view of the human eye and illustration of the distribution of the rods (radiance view; magnitude only), and cones (color: red, green, blue) optical detector cells on the retina and specifically how the fovea is “privileged” in the concentration of cones.

Franck, James (1882–1964)

[biomedical, chemical, optics, quantum] Physicist and chemist from Germany. Franck is known for his theory on the origins of fluorescent transitions and the PHOTOSYNTHESIS. Additionally, James Franck worked with GUSTAV HERTZ (1887–1975; nephew of HEINRICH RUDOLF HERTZ [1857–1894]) on electron collisions and collisions of electrons with atoms of gasses. James Franck along with Gustav Hertz received the Nobel Prize in Physics in 1926 for their work on the confirmation of the BOHR ATOMIC MODEL, demonstrating the discrete ENERGY states of excited electrons in the ATOM.

Franck–Condon principle

[optics, quantum] Description of the dissociation ENERGY transfer of molecular states, first described for a diatomic molecule in 1925 by the physicist and chemist JAMES FRANCK (1882–1964) from Germany, with contributions in 1926 by the QUANTUM mechanical physicist EDWARD UHLER CONDON (1902–1974) from the United States. The classical interpretation involves the consideration that there are no changes in the nuclear configurations associated with the electron energy transitions. The nuclear position changes relatively slow in comparison to the electron transfer. The dissociation can be accompanied by RADIATIVE TRANSFER, providing a fluorescent marker for the transition. The Franck–Condon principle provides a selection rule for spectroscopic analysis, specifically a tool in quantum chemistry. The transitions under the Franck–Condon principle relate the energy interactions between vibronic transitions during PHOTON absorption. The energy transitions take place based on the Schrödinger WAVE solutions for the molecular binding quantum well, which provides the mechanism for the photon interaction. Preferred transitions are between like-wise orientations of the waveform, but at “higher harmonic” levels. The POTENTIAL WELL for the nuclear and electron orbit energy configurations with respect to molecular bindings is shaped according to a parabolic distribution where the “matching” states are quantum harmonic OSCILLATOR waveforms at the various excitation levels ranging from level zero at GROUND STATE to infinity for a free NUCLEON. Exchanges between

vibrational energy levels for the nuclear coordinates are favoring minimal change in nuclear coordinates. The fluorescent excitation process will use incident light of a certain high energy wavelength, which will lose some of its energy at interaction with the Franck–Condon state transition, hence resulting in a lower energy photon emission. The energy loss and resulting longer wavelength is known as the Stokes shift. The energy loss can be measured and provides a direct indication of the energy levels and the “dimensions” of the transition in the molecular configuration. This process can as such be used to map the molecular construction. One example of the Franck–Condon principle with respect to detectable FLUORESCENCE marking from experimental investigation standpoint is found in VISION. Rhodopsin (MOLECULAR WEIGHT ~35,200) is the macromolecule in the RODS (CHROMOPHORE) of the EYE that has a photonic transition at location C-11 (with maximum sensitivity at 500 nm) that takes place on a femtosecond scale. The rhodopsin photon interaction, with temporary energy storage, can be described based on the Franck–Condon principle. The photon interaction with associated changes in ABSORPTION SPECTRUM for an illumination investigating source as part of the chemical processes in rhodopsin can be revealed by absorption SPECTROSCOPY. For rhodopsin, the Franck–Condon energy transfer of the photon interaction is converted in a chemical transition to BACTERIORHODOPSIN within several picoseconds after the photon interaction. This photochemical interaction provides the initiation for the onset of the generation of an ACTION POTENTIAL from a single rod (see Figure F.54).

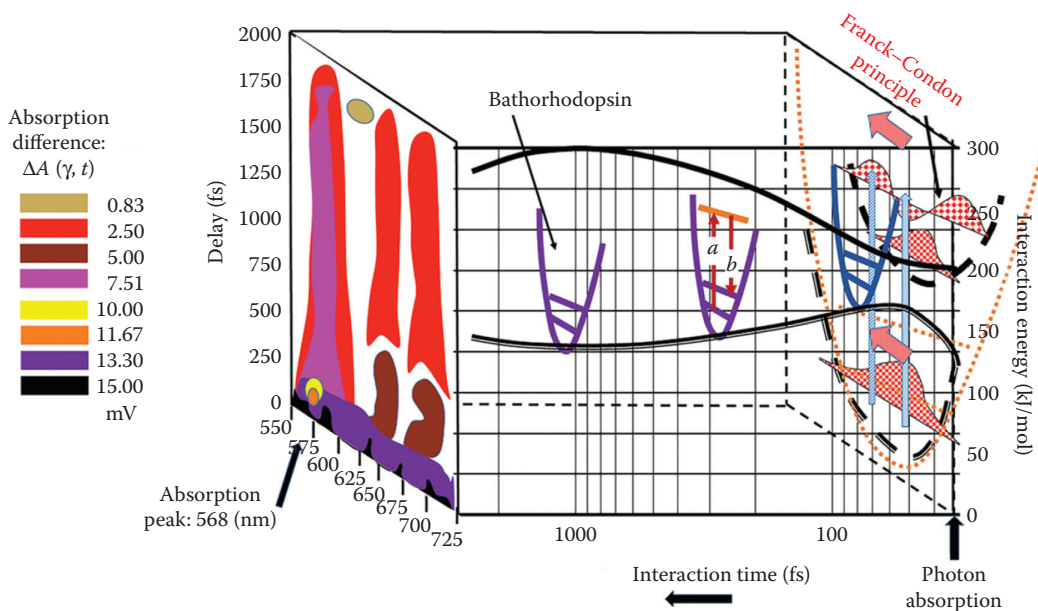


Figure F.54 Franck–Condon principle applied to rhodopsin of biological rod photosensors during interaction of photons within the first 3 fs of the photochemical process leading up to the formation of the action potential with respect to vision. Vibrational transitions in the energy level associated with torque (torsional vibrations) within the C11–C12 position for the rhodopsin molecule (molecular weight: ~35,200).

Franck–Hertz experiment

[atomic] Experimental verification of the discrete electron ENERGY levels by the physicists JAMES FRANCK (1882–1964) and GUSTAV HERTZ (1887–1975), both from Germany. The two scientists were successful in proving the BOHR ATOMIC MODEL and received the Nobel Prize in Physics in 1926 for their efforts.

Franklin, Benjamin (1706/1705?–1790)

[general] American founding father who started out as a printer and became a scientist and statesman for the forming of the United States. Benjamin Franklin acquired significant notoriety as an inventor and scientist. One of his most questionable experiments is the launch of a kite during a thunderstorm (1752) with the intention of attracting LIGHTNING, which could have killed him. These experiments lead to his introduction of lightning RODS on the tops of buildings as a practical deterrent for damage resulting from lightning strikes. During his experimentations, he concluded that there are two types of charges and he separated them as positive and negative. Based on Franklin's assumptions current flows from positive to negative, however the electrons actually migrate from negative to positive potential only. The observation of current as defined by Benjamin Franklin based on the charges applied to GLASS after rubbing it with fur, defined as positive charges by Franklin. Later the current was found to be carried by electrons (negative charges). Additionally, the work of Ben Franklin implied the LAW OF CONSERVATION OF CHARGE, but was not explicitly defined by him (see [Figure F.55](#)).

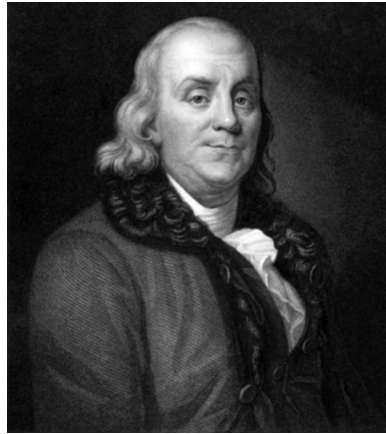


Figure F.55 Benjamin Franklin (1706/1705?–1790). (Courtesy of J. Thomson.)

Franklin

[general] As a unit of charge indicates a force of $F = 1$ dyne ($= 1 \times 10^{-5}$ N) for two charges of 1 Franklin at 1 cm spacing (Coulomb law in Gaussian system: $F = q_1 q_2 / r^2$): $1 \text{ Fr} = 1 \text{ statC} \approx 3.33564 \times 10^{-10} \text{ C}$. It is also referred to as the statcoulomb (*statC*).

Fraunhofer, Joseph von (1787–1826)

[general, optics] Physicist and optician from Germany (Prussian empire). Joseph von Fraunhofer is best known for his documentation of the absorption lines in the solar spectrum, identifying molecular and atomic species. Additionally, the lenses made by Joseph von Fraunhofer were unchallenged in quality. His lenses were used to build perfectly achromatic telescopes (see [Figures F.56](#) and [F.57](#)).



Figure F.56 Joseph von Fraunhofer (1787–1826).

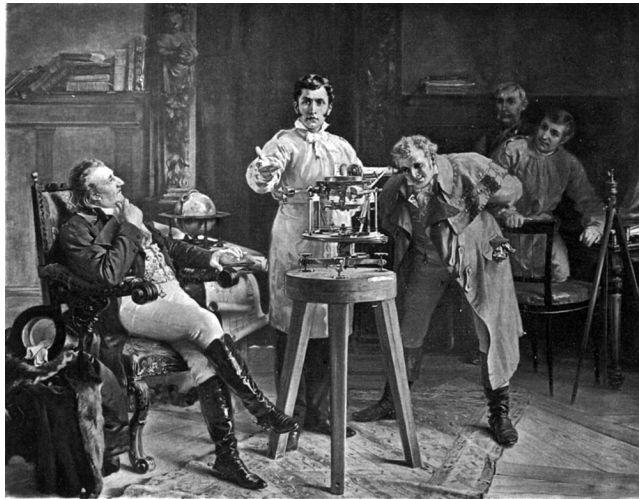


Figure F.57 Artist impression of Joseph von Fraunhofer (1787–1826) with his telescope. (Courtesy of Richard Wimmer, *Essays in Astronomy*. D. Appleton & Company, New York City, 1900.)

Fraunhofer diffraction

[general, optics] Diffraction pattern created in far-field approximation primarily with respect to a single slit. Using Huygens's principle that each location in the space of the slit, with width a , constitutes a source, the sources will form INTERFERENCE. The destructive interference (dark lines) is produced as a function of the illumination WAVELENGTH (λ) in discrete intervals (integer m) with respect to the central optical axis under an ANGLE θ adhering to $\sin \theta_{\text{dark}} = m(\lambda/a)$. The incident rays of ELECTROMAGNETIC RADIATION, or mechanical waves, create an interference at a large DISTANCE where the paths of the rays are considered to be parallel. Compare with the near-field Fresnel diffraction. The secondary sources in within the area of the opening each have a PHASE angle that is slightly different from the neighboring POINT SOURCE increasing

with distance from the edge, providing a vector addition theorem yielding a cord with a length representing the AMPLITUDE of the interference pattern at a specific angle with the normal to the opening (see Figure F.58).

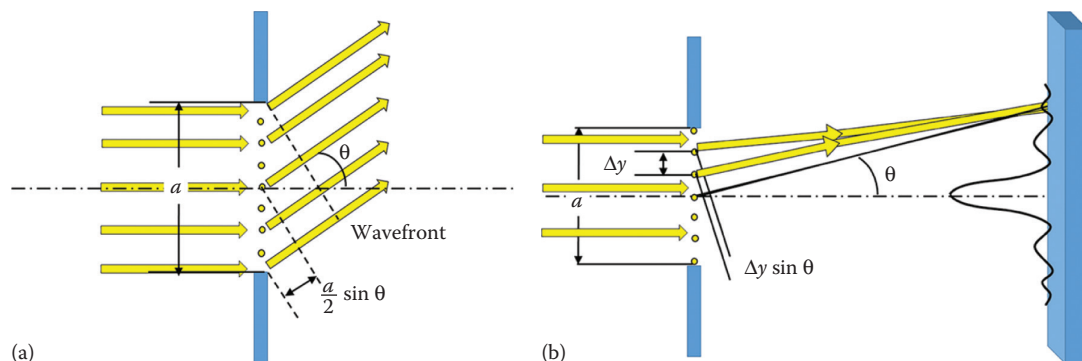


Figure F.58 Geometric representation of the Fraunhofer diffraction slit used to define the Fraunhofer diffraction principle. (a) Single slit where each point in the opening represents a secondary light source and the conditions for positive wave superposition and (b) interference pattern projected on a projection screen.

Fraunhofer lines

[astronomy/astrophysics, atomic, optics] Spectral absorption lines in the solar emission named after JOSEPH VON FRAUNHOFER (1787–1826), who documented these findings in 1814. These spectral omission lines are found ranging from the ULTRAVIOLET, starting at approximately 180 nm far into the INFRARED up to 20 μm . Each specific lines represent certain atomic and molecular transitions with respect to ENERGY transferred during absorption. The recognized shift in emission wavelength can be used as an indication of surface temperature effects, for instance, the shift for the carbon absorption at 538.03 nm (*also see* ZEEMAN EFFECT) (see Figure F.59).

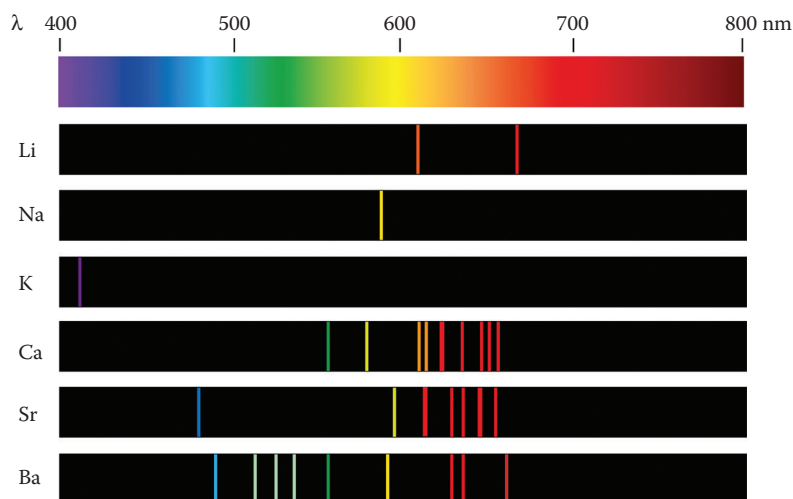


Figure F.59 Fraunhofer lines emitted by various elements.

Free charge

[electronics, general] The classical model of electrical conduction in metals based on the free migration of electrons was first proposed by Paul Drude (1863–1906) in 1900. This model was followed by OHM'S LAW, which describes resistivity related to the MOTION of atoms in place with respect to the free movement of electrons in conductors, in particular metals. The thermal atomic/MOLECULAR MOTION increases the RESISTANCE to higher incidence of collisions with the electron migration. Conduction in a material with free electrons relies only on the DRIFT VELOCITY of the electrons, however since the CONDUCTOR is filled with electrons, the relation to an emerging electron resulting from an electron entering from an electromotive force source is virtually instantaneous over any length. Free electrons can move from the VALENCE BAND to the CONDUCTION BAND of the ENERGY configuration of the material with little effort, or are occupying the conduction band due to very loose forces holding the external electron(s).

Free spectral range

[optics] In interferometry, specifically applied to a Fabry–Pérot étalon, the full-width half maximum spectral line separation ($\Delta\lambda$) between consecutive INTERFERENCE maxima is a device constant written as $\Delta\lambda = \lambda_0 / (2n\ell \cos\theta + \lambda_0) \cong \lambda_0 / 2n\ell \cos\theta$, where the central wavelength of the maximum is λ_0 , the étalon has refractive index n and thickness ℓ and light enters at an ANGLE θ .

Freezing

[general, thermodynamics] Temperature where solid and LIQUID are in equilibrium. The process of freezing requires the removal of ENERGY from a liquid, defined at the enthalpy of SOLIDIFICATION, or enthalpy of FUSION (h , generally a positive value, except for helium, which requires the addition of heat to fuse), also known as the LATENT HEAT OF FUSION. For water the fusion heat is $h_{f,H_2O} = 333.55$ kJ/kg. Adding a SOLUTE to a liquid (the SOLVENT) will decrease the freezing point. This “freezing point depression” is widely used in deicing of planes and on the road surface during snow or freezing RAIN. The freezing point depression (ΔT_F) can be described in first-order approximation based on the solvent nature (expressed by the cryoscopic factor $K_F = RT_F m_M / \Delta h_f$, where $R = 8.3144621(75)$ J/Kmol the GAS constant, T_F the freezing point of the solvent, m_M the MOLAR MASS of the solvent, and Δh_f the molar heat of fusion change for the solvent), the VAN'T HOFF FACTOR (Π_{osm}), the molar concentration of the solvent ($[S]$), as $\Delta T_F = K_F \Pi_{osm} [S]$. A more detailed analysis yields $\Delta T_F = \Delta h_f - 2RT_F \ln(a_{liq}) - \sqrt{[2\Delta c_p^{\ell s} T_F^2 R \ln(a_{liq}) + (\Delta h_f)^2] / 2((\Delta h_f / T_F) + (\Delta c_p^{\ell s} / 2) - R \ln(a_{liq}))}$, where $\Delta c_p^{\ell s}$ is the change in SPECIFIC HEAT (under constant pressure between the liquid and the solid PHASE and a_{liq} represents the ACTIVITY of the SOLUTION, a function of the ionic length (determined from the Pitzer model, which ties the activity to the GIBBS FREE ENERGY (G) and the CHEMICAL POTENTIAL (μ_i) of the respective constituents, as $G = \sum_j \mu_{ij} + RT \ln(b_i a_{liq})$, where b_i is the molality) (see Figure F.60).

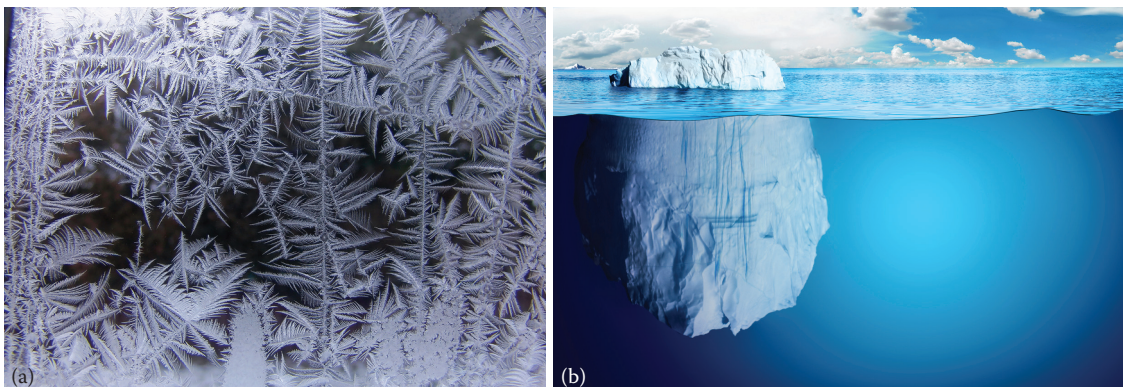


Figure F.60 (a) Water vapor frost deposition of window. (b) Illustration shows frozen water has a density of 0.9 times that of liquid water as the iceberg floats partially submerged (90%).

Frequency (ν)

[general] The number of cycles, revolutions, or vibrations completed in a unit of time, specifically per SECOND, expressed in Hertz (Hz). Frequency is the reciprocal period of a recurring (e.g., OSCILLATION) event. The unit Hertz is derived from the physicist HEINRICH HERTZ (1857–1894) from Germany, who introduced pioneering contributions to the understanding and description of RADIO waves. Frequency is associated with a real WAVE or the graphical representation of the periodic phenomenon yields a waveform. Frequency is correlated to the WAVELENGTH (λ) and speed of propagation (v ; for light $c = 2.99792458 \times 10^8$ m/s) as $\nu = v/\lambda$.

Whistling, using only the lips of the mouth, can produce a single frequency acoustic wave in most cases.

Frequency also applies to discrete phenomena that occur at regular intervals, such as the delivery of the mail as once per day. Many phenomena are indicated by the base frequency in order to define the recurrence, such as the average HEART rate for a person at rest at approximately 65 beats per minutes, which provides a frequency of slightly greater than 1 Hz, while the *frequency spectrum* is defined by at least the first eight harmonics for the electrical ECG SIGNAL associated with the heart rate (*also see* DOPPLER EFFECT) (see [Figure F.61](#)).



Figure F.61 Milkman delivering the milk at a frequency of once per day.

Frequency, angular (ω)

[general] The expression of a repetitive phenomenon in graphical format provides a sine WAVE, which is directly linked to a circular MOTION. Expressing the temporal AMPLITUDE evolution in FREQUENCY (ν) is hence directly tied to the angular velocity, expressed in radians per SECOND $\omega = 2\pi\nu$. The angular velocity is linked to the tangential VELOCITY (v) as a function of the radius to the axis of rotation (r) as $v = r\omega$ (see [Figure F.62](#)).



Figure F.62 A record player with vinyl record with engraved musical pattern that rotates with constant angular velocity, the tangential velocity on the outer radius will be greater than the tangential velocity closer to the center of the rotating disk.

Frequency, resonant (ν_0)

[general] Frequency at which a system will oscillate when it is not driven. Examples of OSCILLATION frequencies for specific systems are PENDULUM of length L : $\nu_0 = (1/2\pi)\sqrt{(g/L)}$, where g is the GRAVITATIONAL ACCELERATION; MASS (m) on a spring with spring constant k : $\nu_0 = 1/2\pi\sqrt{(k/m)}$; CAPACITOR (C)–INDUCTOR (L) circuit $\nu_0 = (1/2\pi)(1/\sqrt{LC})$; and the resonant frequencies of a string with linear mass density $\mu_\ell = m/\ell$ (mass m ; length of string ℓ), under tension F_T providing base frequency ($n = 1$) and higher harmonics ($n = 1, 2, 3, \dots$): $\nu_n = (n/2\ell)\sqrt{(F_T/\mu_\ell)}$. Note that on a string instrument the frequency of the VIBRATION can be altered by changing the length of the string under placement of the fingers, or by changing the tension as applied for tuning purposes. The frequency aspects of the string with regard to tension were described by the French scientist and priest MARIN MERSENNE (1588–1648) (the “father of ACOUSTICS”) in 1627. Alternatively, the resonant frequency defines the frequency at which the AMPLITUDE will reach excessive large MAGNITUDE when driven by external force. It is also referred to as “NATURAL FREQUENCY.”

Frequency hopping spread spectrum (FHSS)

[communication, computational, general, signal] In frequency hopping transmission, the electromagnetic emission source (RADIO wave, telecommunications; mobile phone) applies a specific (predetermined) “hopping” pattern, continuously changing the CARRIER frequency. The changes in transmission frequency are applied in a pseudorandom sequence, applied to both the transmitter and the receiver stations. The advantage is that the SIGNAL uses a different transmission channel with an accompanying different set of interfering signals during each hop. This process has the following two main advantages: (1) it avoids failing communication at a particular frequency, because of a fade or a particular interferer and (2) the receiving station is dedicated to the transmitter. The “dedication” avoids any other party from “tuning in” to the data transmission/conversation, thus providing protection from unauthorized access. In a similar fashion, this process prevents a mobile phone user to listen to the conversations of anyone standing in any proximity to the sender or receiver, respectively, obtain no unauthorized details from a data transmission. The concept was introduced by the movie STAR HEDY LAMARR (1914–2000) in 1941, during World War II (1940–1945) to provide guidance during the launch and trajectory of a torpedo, ensuring and maintaining and correcting course and guarantee a delivery to the target location. The early mechanism was based on musical instruments, specifically the mechanical organ, or player PIANO (pianola), electronic carillon, or other various types of orchestrion. The orchestrion (Carillion; barrel organ hurdy gurdy) uses a role of paper with holes punched in a certain pattern that engage the keys on the instrument for a specific note when the hole passes the trigger switch. The “music role” encoding concept can be traced back to approximately 1877, Cambridgeport, MA. Other mechanisms using spikes/bumps on a METAL drum or disk,

such as used in a music box, which was reportedly first used in the early ninth century in the Persian Empire (now known as Iraq) (see [Figure F.63](#)).



Figure F.63 (A) Musical instrument that uses the principle of “frequency-hopping” based on the fact that a roll with holes will engage a single instrument with the passing of a hole, hopping from note to note. The paper roll is advanced by rotating a wheel attached to an axle that winds the roll. This formed the basis of the concept introduced by Hedy Lamarr (1914–2000) and George Antheil (1900–1959) in 1942. (B) Musical instrument, “music-box” that uses the principle of “frequency-hopping” based on the fact that a disk with knobs engages a single chime with a distinct respective note on passing.

Frequency modulation (FM)

[electromagnetism, general] Principle of data encoding used in RADIO transmissions and other electromagnetic, and acoustic WAVE emissions as well as imaging based on superposition of a range of frequencies on top of a CARRIER WAVE (alternatively, inscribed in a baseline pattern). Frequency modulation primarily applies to analog data transfer. FM was introduced by an electrical engineer, Edwin Howard Armstrong (1890–1954), from the United States in 1933. A decoder is used to tune in to the carrier frequency and subsequently the imbedded SIGNAL is filtered out. Radio-frequency (RF) modulation is using carrier waves with a frequency range of 85–108 MHz. Television broadcasts were generally frequency modulated signals but in several countries the analog encoding has been changed to a digital format. In the transmission of radio signals, the use of frequency modulation provides a high bandwidth frequency encoding with the ability to send two channels within the same carrier wave bandwidth in order to achieve stereophonic SOUND after electronic decoding by the RADIO RECEIVER. STEREO encoding for radio transmission and listening was introduced

in the late 1950s. In acoustical imaging frequency modulation of the pressure wave signal applied by the piezoelectric crystal provides the means for analysis of material properties based on DISPERSION effects. Piezoelectric crystals will act as adjustable INDUCTOR–capacitor circuits (LC tuner), with respective resonant frequency tuning range. The modulated frequency (ν_m) pattern on carrier frequency ν_c will adhere to the following expression: $\nu_{FM} = \nu_c - \nu_m \beta_m \cos(2\pi \nu_m t)$, where β_m is the modulation index (~efficacy). The piezoelectric tuning is used both for recording (MICROPHONE) and ULTRASONIC IMAGING. Frequency modulation can be generated by means of a voltage-controlled OSCILLATOR in the form of an integrated circuit. The signal collection is generally performed by a inductor–capacitor circuit, with variable capacitance (tuner dial turns the parallel plate CAPACITOR to change the plate area and hence changes the capacitance; other digital tuning mechanism are available through INTEGRATED CIRCUITS). A frequency DEMODULATOR involves, for instance, the use of a PHASE-LOCKED LOOP, also incorporated in integrated circuit design (see Figure F.64).

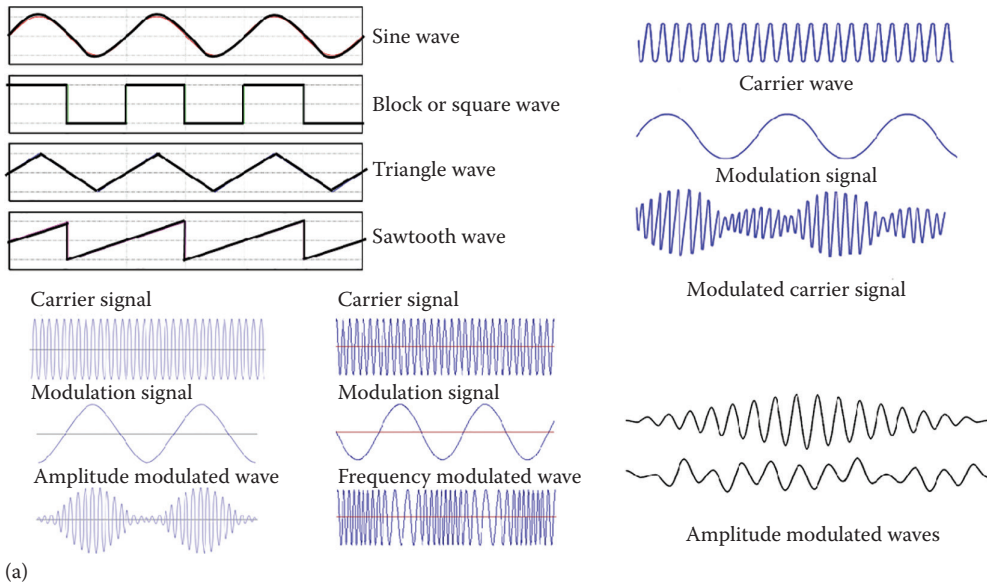


Figure F.64 (a) Graphical illustration of frequency modulation. Frequency outline: waveforms ranging from sinusoidal wave, sawtooth, and block wave. The sawtooth and block wave are composed of a broad range of (sinusoidal) frequencies (ν); with associated wavelengths: $\lambda = \nu/\nu$, ν the velocity of propagation for the wave; that can be decomposed by Fourier transform and (b) Edwin Armstrong (1890–1954).

Frequency spectrum

[general] The range of RADIATION from sources in various modalities, ranging from electromagnetic, to pressure (acoustic). The ELECTROMAGNETIC SPECTRUM ranges from 300 EHz in the gamma radiation to single digit Hz in the extreme low frequency band, beyond the general spectrum of RADIO waves. The acoustic frequency spectrum has a range of decimal Hertz (rumbles in the EARTH'S CRUST), to the echo scanning by bats (several hundred kilohertz) and to several hundred megahertz for ULTRASONIC IMAGING and vibrational disintegration (e.g., breaking KIDNEY stones) (*also see* ELECTROMAGNETIC SPECTRUM, EAR, and HEARING).

Fresnel, Augustin-Jean (1788–1827)

[general, optics] Physicist from France. Fresnel verified the WAVE phenomenon for light (ELECTROMAGNETIC RADIATION) in 1818. Fresnel's work on diffraction and INTERFERENCE provided the fundamentals for modern coherent and noncoherent imaging as well as general optical ray-tracing techniques. Fresnel performed experimental verification of the POLARIZATION concepts introduced by Christiaan Huygens (1629–1695), based on the transverse-wave phenomenon introduced by Huygens (see [Figure F.65](#)).



Figure F.65 Augustin-Jean Fresnel (1788–1827).

Fresnel diffraction (1788–1827)

[general, optics] Diffraction pattern created in near-field approximation. The incident rays of ELECTROMAGNETIC RADIATION, or mechanical waves, create an INTERFERENCE at close DISTANCE where the paths of the rays are considered to originate from a POINT SOURCE, or the diffraction is observed in a small observation point. Compare with the near-field FRAUNHOFER DIFFRACTION. The Fresnel LENS yields a significant consequence of the work of AUGUSTIN-JEAN FRESNEL (1788–1827), specifically applied to lighthouse lights for focusing large beams (see [Figure F.66](#)).



Figure F.66 Illustrations of the use of the Fresnel diffraction in the special lens type known as a Fresnel lens, primarily used in lighthouses and automobile headlights.

Fresnel number ($N_F = a^2/\lambda z$)

[computational, fluid dynamics, general] Dimensionless number that provides the validity of approximation that a SPHERICAL WAVE becomes a PLANE WAVE, which is the asymptotic value, where a is the diameter of the beam at the source (e.g., hole in panel shielding LIGHT SOURCE), λ the wavelength of the light, and z the DISTANCE from the source in the direction of propagation. In a laser cavity a large Fresnel number implies minimal diffraction phenomena.

Fricative consonant

[acoustics, fluid dynamics, mechanics] Turbulent FLOW pattern of AIR in the creation of a SOUND. The TURBULENCE is caused by fluids flowing through a narrowly spaced opening at high velocity. The turbulence creates eddies with inherently random pressure fluctuations that are equivalent to aperiodic sound patterns. In speech, this mechanism references the formation of a consonant that has a sound resulting from forcing air between two tightly spaced objects in the vocal tract, such as the teeth or the tongue and teeth, also referred to as fricatives (*also see* COEFFICIENT OF FRICATION).

Friction

[computational, fluid dynamics, general] Resistive force with respect to two or more media in MOTION with respect to each other. Generally, the friction force is a linear function of the normal force applied by one object with respect to the orthogonal force applied by another object, such as a box sitting on the GROUND. The NORMAL FORCE ($F_N = ma$ [mass m multiplied by acceleration a]) serves as maintaining the equilibrium, provided that there is no motion in the direction of the partition. The proportionality factor is the friction coefficient, separated in static and dynamic conditions as μ_s and μ_d , respectively. The friction force in this situation is $F_f = \mu F_N$, in opposite direction of motion. The coefficient of friction is most often a function of temperature, which is why racing cars will warm up both the engine (to minimize the gaps by allowing for optical THERMAL EXPANSION and fit) and the tires for maximum ADHESION to the road surface. Solid-on-solid friction can be modified by introduction of a FLUID; for instance, a FLOW of AIR or a LIQUID/gel lubricant). Teflon has remarkably low surface friction and is used in many designs as a coating or the material choice, also in various other ELASTOMERIC forms (e.g., fluoroplastics: PTFE [polytetrafluoroethylene], FEP [fluorinated ethylene propylene], PFA [perfluoroalkoxy]; Slick50®, etc.). When a body rolls and either/both body deforms

(e.g., tire on road surface; rolling-pin on bread dough) there will be additional friction associated with the deformation ENERGY, expressed by the deformation constant μ_r in the same format $F_f = \mu_r F_N$. Coefficients of frictions can be found in tables listed in many ENGINEERING handbooks, for specific conditions and materials. The surface interaction between a fluid and a solid is captured by the VISCOSITY (η_k , the KINEMATIC VISCOSITY; η_s , the static viscosity; stagnant flow) of the fluid, while the SURFACE ROUGHNESS introduces additional restrictive influences. The surface roughness is captured by the DRAG COEFFICIENT D_{drag} , representing the drag force (F_D) over a surface area A for a fluid with density ρ , while traveling at velocity v , expressed as $F_D = D_{\text{drag}} A (\rho v^2 / 2)$. The drag coefficient is a function of the MAGNITUDE of the height of the surface “bumps,” and the size distribution, next to the REYNOLDS NUMBER, the Froude number, and the MACH NUMBER. In terms of Reynolds number (Re) for flow, the expression for drag becomes $D_{\text{drag}} = (Re/24)(1 + 0.15Re^{0.687})$, for flow $Re = \rho v d_p / \eta$ (d_p the PARTICLE diameter in colloid SOLUTION, respectively the average size of bumps/dips [e.g., GOLF BALL] on surface, and v the flow velocity at the point of contact). Roughness is generally indicated by the roughness parameter, the relative size of the unevenness (δ_s) on the surface to the size $2r_o$ (radius of curvature) of the object in the flow $\delta_s / 2r_o$. Friction under repetitive motion provides a damped OSCILLATION (*also see POISEUILLE’S LAW*) (see Figure F.67).



Figure F.67 Friction generating enough heat to provide the initiation of the exothermic oxidation of sulfur in a match tip. The composition of the “safety” match head is actually sulfur, mixed with glass powder, as well as an oxidizing agent (catalyst).

Friction factor ($f = \Delta P / [(L/D)((1/2)\rho v^2)]$)

[mechanics] Dimensionless number pertaining to the influence of WALL SHEAR STRESS in FLUID FLOW calculations. The FRICTION factor depends on two other DIMENSIONLESS NUMBERS: the SURFACE ROUGHNESS (relative ROUGHNESS to be exact) and the REYNOLDS NUMBER (Re). In the expression, the following conventions are used: ΔP , the PRESSURE drop over the entry into a PIPE with diameter D and length L , and ρ , the FLUID DENSITY with v the FLOW VELOCITY. SURFACE ROUGHNESS influence the mathematical approach since there will be a transition to TURBULENT FLOW with increasing roughness, while the friction primarily applies to LAMINAR FLOW. The friction factor can also be included in calculation of the HAGEN–POISEUILLE EQUATION.

Friedmann, Alexander Alexandrovich (“Aleksandr Fridman”) [Алекса́ндр Алекса́ндрович Фри́дман] (1888–1925)

[astronomy/astrophysics, computational] Scientist, astrophysicist, and mathematician from the USSR (Soviet Russia). The theoretical efforts of Friedmann showed that the UNIVERSE is expanding and is related to the work of his contemporary GEORGES LEMAÎTRE (1894–1966) and is referred to as the “BIG BANG THEORY,” described by the “FRIEDMANN EQUATIONS” (see Figure F.68).



Figure F.68 Alexander Alexandrovich Friedmann (“Aleksandr Fridman”) (1888–1925) (Cyrillic, russian: Алекса́ндр Алекса́ндрович Фри́дман).

Friedmann equations

[astronomy/astrophysics, computational] Mathematical expressions with respect to the EXPANSION of the UNIVERSE, within the context of general relativity. The Friedmann equation is based on the hypothesis that the universe is homogeneous and isotropic, the cosmological principle. ALEXANDER FRIEDMANN (1888–1925) published his approximation in 1922, based on the works of ALBERT EINSTEIN (1879–1955) on GRAVITATIONAL FIELD equations. The equation defines the dimensional proportions (r) of the universe with respect to TIME (t) as indication of the galactic evolution based on the assumption $dr^2 = a(t)^2 dr_3^2 - c^2 dt^2$, where the term dr_3^2 defines space in one of three configurations: (1) a hyperbole with negative curvature ($k_F = -1$), (2) two-dimensional flat ($k_F = 0$), or (3) a sphere ($k_F = 1$); $a(t)$ represents a scaling factor (for $k_F = 0$, flat space $a(t) = a_0 t^{2/3(\zeta+1)}$; ζ a boundary condition: $\zeta = 0$ defines “MATTER”-dominated space, and $\zeta = 1/3$ defines RADIATION dominated space) and a_0 is an integration constant, depending on the assumption about the initiation of the universe: $t = 0$ (“BIG BANG THEORY”). The Friedman equations state $(\dot{a}(t)^2 + k_F c^2)/a(t)^2 = (8\pi G \rho + \Lambda c^2)/3$, with G Newton’s gravitational constant, density $\rho \sim 0.2 \text{ atoms/m}^3$ (note that the critical universe density is approximately $\rho_c = 5 \text{ atoms/m}^3$), Λ the cosmological constant, and c the speed of light. In this definition, the Hubble parameter is incorporated as $H_{\text{Hub}} = (\dot{a}(t))/a(t)$ ($\dot{a}(t) = \partial a(t)/\partial t$), the special curvature is defined by $r_{\text{univ}} = k_F/a(t) = (1/6)R_{\text{Ricci}}$, where in the Friedmann model the Ricci curvature scale is defined as $R_{\text{Ricci}} = (6/c^2 a(t)^2)(\ddot{a}(t)a(t) + \dot{a}(t)^2 + k_F c^2)$, and the second equation $\ddot{a}(t)/a(t) = -(4\pi G/3)(\rho + (3P/c^2)) + (\Lambda c^2/3)$ with $P = \wp \rho c^2$ the pressure ($\wp$ a NORMALIZATION constant).

FROG

[optics] Acronym for frequency resolved optical gating. Imaging technique used in ultrafast laser pulse interaction, applying gating to perform time-resolved spectral information (see [Figure F.69](#)).

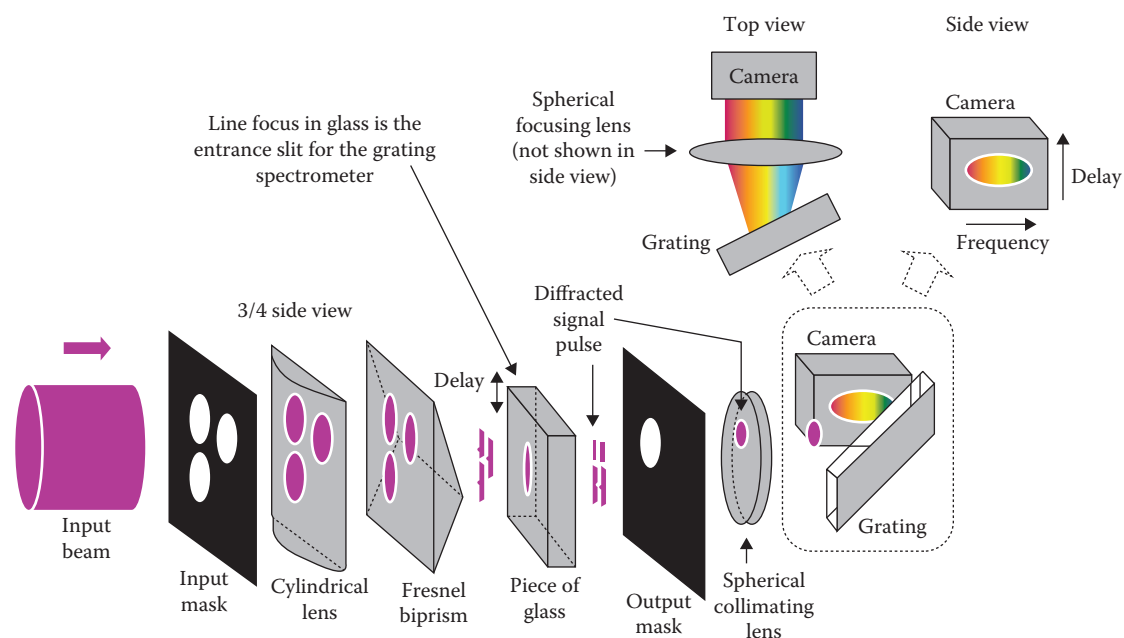


Figure F.69 FROG imaging technique.

Froude, William (1810–1879)

[fluid dynamics] Scientist and architect from Great Britain. William Froude established expressions for the derivation of FLOW resistance in the design of ships. He is most known for his “hull speed equation,” relating to the length of the waterline at the hull (L_{wl}) yielding a VELOCITY (v_{Hull}) for which the bow WAVE (the wavelength of the perturbation at the bow of the ship on the water surface) equals the length of the ship, providing the empirical relation $v_{Hull} \cong 1.34 \times \sqrt{L_{wl}}$. His other contributions are in DIMENSIONLESS NUMBERS for the ratio of forces (see [Figure F.70](#)).



Figure F.70 William Froude (1810–1879).

Froude number ($Fr = v^2/gL$)

[fluid dynamics, geophysics] Dimensionless number relating the inertial forces in the ratio to gravitational force, where v is the FLOW velocity, g the GRAVITATIONAL ACCELERATION, and L the characteristic length of the phenomenon under investigation. Introduced by WILLIAM FROUDE (1810–1879). Under certain circumstances the Froude number can be used to interpret the ratio of mean flow velocity with respect to the propagation velocity of a SURFACE GRAVITATIONAL WAVE.

Froude's law of similarity

[fluid dynamics] The wave RESISTANCE of an equivalent model of an object in FLOW is equal only when the Froude number is equal from model to reality. Postulated by WILLIAM FROUDE (1810–1879), this applies to the WAVE resistance only, when involving total resistance this would include frictional resistance as well. The LAW OF SIMILARITY would describe the equivalence of a model ship to a real ship.

Fuel cell

[chemical, energy, solid-state, thermodynamics] ENERGY storage and supply mechanism based on the principles of OXIDATION and resulting release of free electrons discovered by the German chemist and scientist Christian FRIEDRICH SCHÖNBEIN (1799–1868) published in 1838. Schönbein was experimenting with ELECTROLYSIS of water, producing oxygen (in fact ozone was part of the product) and hydrogen. This process, when controlled, can be reversed to produce ELECTRICITY, however when uncontrolled it form a HYDROGEN BOMB with considerable explosive energy. An additional accidental discovery of Schönbein was the accidental spill of two liquids: nitric ACID and sulfuric acid, which mixed and were collected with a cotton rag. The soaked cotton spontaneously ignited based on the internal release of oxygen from the nitro group combining with the CELLULOSE generated by the sulfuric acid from the cotton (see [Figure F.71](#)).



Figure F.71 Hybrid automobile that relies on hydrogen fuel cell for generation of energy to be converted into translational energy.

Fugacity ($\pi_f(T, P)$)

[thermodynamics] Two-phase equilibrium of a LIQUID substance with its GASEOUS STATE that is not conforming to the IDEAL GAS LAW $\pi_f(T, P) = \pi_f(T, P_0) \exp[(\mu_f(T, P) - \mu_f(T, P_0))/RT]$, a slight deviation from the ideal gas law $PV = nRT$, and the transformation of the CHEMICAL POTENTIAL $\mu_f(T, P)$. For an IDEAL GAS, the chemical potential relates to the VOLUME (V) through the PRESSURE (P) derivative, as a function of TEMPERATURE T as $(\partial \mu_f(T, P)/\partial P)_T = V = RT/P$ and gas constant $R = 8.3144621(75) \text{ J/Kmol}$.

Fugacity coefficient

[thermodynamics] Ratio of FUGACITY ($\pi_f(T, P)$) to PRESSURE (P): $c_F = \pi_f(T, P)/P$, used as indication of MAGNITUDE of deviation from IDEAL GAS behavior.

Fulcrum

[biomedical, engineering, mechanics] Pivot point, as found for a seesaw or draw-bridge (see [Figure F.72](#)).



Figure F.72 Fulcrum concept of a drawbridge in the Netherlands.

Fuller, Richard Buckminster (1895–1983)

[computational, general, mechanics] Architect and scientist from the United States. Fuller may be best known for his geometric frame design that uses minimal materials with maximum force, specifically used in the construction of the geodesic dome under his design. Based on his work certain intricate carbon structures were named fullerenes (*see* **BUCKMINSTER FULLER, RICHARD**).

Functional MRI (fMRI)

[biomedical, biophysics, electromagnetism, energy, engineering, imaging, instrumentation] (Established: 1991) Imaging methodology that uses the hemodynamic and metabolic activities in a biological system for identification of functional disorders and chronic illnesses. It is used to determine the cellular METABOLIC ACTIVITY using a mechanism of radio-frequency modulated MAGNETIC FIELD probing of a biological system and collecting the re-emitted spectrum as a function of location and time. The fMRI distinguishes itself from regular MRI in the fact that the phenomena are time resolved [function], whereas regular MRI is a stationary imaging technique. The IMAGE is reconstructed using the (Fourier-) SLICE theorem, which entails every set of parallel scans at ANGLE θ will produce the values of $F(u, v)$ along one line in the frequency plane (u, v) . The Fourier slice theorem can be described in the following two steps: Step 1—create a set of parallel scans at angle θ and produce the projection function $P_\theta(t)$. Step 2—calculate the one-dimensional FOURIER TRANSFORM of the projection function $P_\theta(t)$ to produce the MAGNITUDE of $F(u, v)$ along a line passing through the origin with angle θ with u-axis. See Functional MRI for detailed information (also see magnetic

resonance imaging [MRI]). MRI used the SPIN of hydrogen nuclei as the tool for anatomical imaging. The spin has a PRECESSION which can be altered under influence of an externally applied resonant (frequency modulated: RF band) magnetic field. Once the external drive is removed, the hydrogen will return to its original ENERGY state, with the release of the stored energy as RF RADIATION emitted at the Larmor frequency. MRI works without the need for pharmacologic markers, although these are being developed to increase the imaging repertoire; neither radioactive isotopes are required. fMRI is based on MRI technology and is applied specifically for brain function analysis and for the isolation and noninvasive diagnosis of cancer. fMRI uses the variability in BLOOD supply in support of the local METABOLISM while providing a strong RF SIGNAL. By physical stimulation of specific biological functions (VISION: checkerboard), or activities (finger tapping), certain segments of the brain will become more active at the time of stimulation, which will appear under fMRI based on the cellular blood supply and interstitial blood content. Based on the higher metabolic activity of cancer than for healthy tissue, the first indication for the presence of cancer is determined. Several types of cancer have additional functional features that are very different from healthy tissues and allow for more specific analysis. In particular, certain cancers use a cyclic mechanism of mimicking impeding CELL death to encourage the surrounding tissue to institute a healing process. The healing process included increased blood vessel formation, providing enhanced PERFUSION with resulting increase in transportation, and delivery of nutrients and oxygen. As a result, the simulating cancer cluster will have created an enhanced environment for growth and will revive and grow with increased vigor. This process may repeat itself and may do so for an extended frequency of revivals. Under long-term (repetitive screening with set intervals) follow-up by fMRI diagnostics, the cancer can be analyzed and the volumetric extend as well as rate of growth can be established for prognosis and evaluation of treatment options. MRI is a tomographic imaging technique that produces images of internal physical and chemical properties of the body by measuring the emitted nuclear magnetic resonance (NMR) signals. In a typical MRI exam, the patient lies inside the machine and a RF-modulated magnetic signal is emitted into the patient body, which responds by emitting another RF signal. The received signal is recorded and processed to yield the MRI image. The NMR phenomenon was reported by FELIX BLOCH (1905–1983) and EDWARD MILLS PURCELL (1912–1997) in 1946 (for which they received the Nobel Prize in Physics) based on the BLOCH EQUATIONS for the temporal evolution of magnetization. In 1973, MRI was made possible by PAUL CHRISTIAN LAUTERBUR (1929–2007) and Sir Peter Mansfield (1933–) (see MAGNETIC RESONANCE IMAGING for additional information) (see [Figures F.73](#) and [F.74](#)).

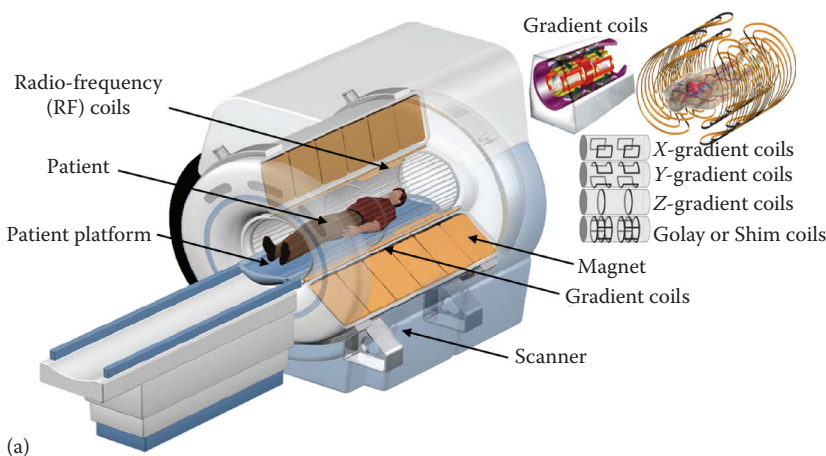


Figure F.73 (a) MRI machine diagram.

(Continued)

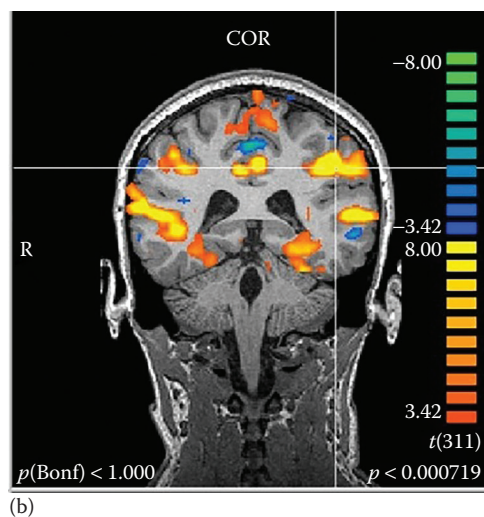


Figure F.73 (Continued) (b) False color image of brain activity acquired from MRI scan procedure under the performance of certain tasks. (Courtesy of the University of Missouri, Columbia, MO.)



Figure F.74 Functional magnetic resonance imaging (fMRI) room. (Courtesy of Siemens Healthcare.)

Functional residual capacity (FRC)

[biomedical, fluid dynamics] The amount of GAS that remains in the lungs after normal exhalation during TIDAL BREATHING. Functional residual capacity and other tidal breathing parameters can be measured with a spirometer.

Fundamental frequency

[acoustics, computational, general, imaging, optics, quantum] Baseline frequency. Lowest frequency of a set of harmonics. The fundamental frequency generally conforms to a match in half wavelength or quarter WAVELENGTH (single-ended open system, providing the crest at the opening vs. equilibrium [zero displacement] at the closed end) to the system parameters, either mechanically or energetically as well as QUANTUM mechanically. In FOURIER ANALYSIS, the fundamental frequency is the base frequency that defines the periodic event (whole wavelength).

Fundamental particles

[atomic, high-energy, nuclear, solid-state] The current consensus on nuclear composition is that sub-nuclear particles are composed of clusters containing two or more units called quarks. There are three fundamental PARTICLE types: the electron (which is a LEPTON), the d-quark (“down”-quark), and the u-quark (“up”-quark). The strong force interaction between the quarks creates neutrons, pions, protons, and more ELEMENTARY PARTICLES. These quarks along with the NEUTRINO (which is a lepton) are considered the FIRST GENERATION OF MATTER. With increased ENERGY states there are additional particle configurations in the second and third generation, respectively.

Fundamental wave

[acoustics, mechanics] The frequency in a string with mass m and length ℓ under TENSION (T_s) will reverberate at several harmonic states (n_{harm}), with $n_{\text{harm}} = 1$ providing the lowest resonance FREQUENCY (v): $v_{n_{\text{harm}}} = (n_{\text{harm}}/2\ell)\sqrt{(T_s/(m/\ell))} = n_{\text{harm}} v_1$, the $n_{\text{harm}}^{\text{th}}$ harmonic will be composed of n_{harm} ANTINODES. On a cello (or other string instrument) the tone will change (increase in PITCH, higher tone) when a string is depressed against the neck of the instrument and hence shortened.

Fusion

[nuclear] Merging of two or more nuclei, short for nuclear fusion. Nuclear fusion is the source of ENERGY for stars, and additionally used in the HYDROGEN BOMB. When two nuclei bond together to form a more massive NUCLEUS, the BINDING ENERGY per nuclide increases. The binding energy can be released based on ALBERT EINSTEIN'S (1879–1955) postulate $E = mc^2$. In stars, two protons (${}^1_1\text{H}$) (with charge $e = 1.60217657 \times 10^{-19} \text{ C}$) will overcome their Coulomb repulsion and join (at separation r) with energy $\text{PE} = k_e(e^2/r)$, with

Coulomb's constant: $k_C = 1/(4\pi\epsilon_0)$, where: $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space. The process is described as ${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^2_1\text{D} + {}^0_{-1}\text{e} + \nu_e$, forming deuterium ${}^2_1\text{D}$, with emission of a NEUTRINO ν_e , and a positron ${}^0_{-1}\text{e}$. Subsequently, a deuterium PARTICLE will merge with a PROTON to form 3-Helium (${}^3_2\text{He}$): ${}^2_1\text{D} + {}^1_1\text{H} \rightarrow {}^3_2\text{He} + \gamma$, releasing gamma RADIATION. The final stage of the fusion process is the formation of 4-Helium: ${}^3_2\text{He} + {}^3_2\text{He} \rightarrow {}^4_2\text{He} + {}^1_1\text{H} + {}^1_1\text{H}$; releasing the substantial amount of energy of 26.7 MeV per four protons. These conditions are made possible due to the excessive high temperature of the stellar proton gas: (using the kinetic energy $KE = (3/2)k_bT$, Boltzmann coefficient: $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$) $T = 1 \times 10^9 \text{ K}$. It is also known as THERMONUCLEAR FUSION. The SUN as a whole releases in excess of $3.8 \times 10^{26} \text{ J/s}$, with only a fraction reaching EARTH (see [Figure F.75](#)).

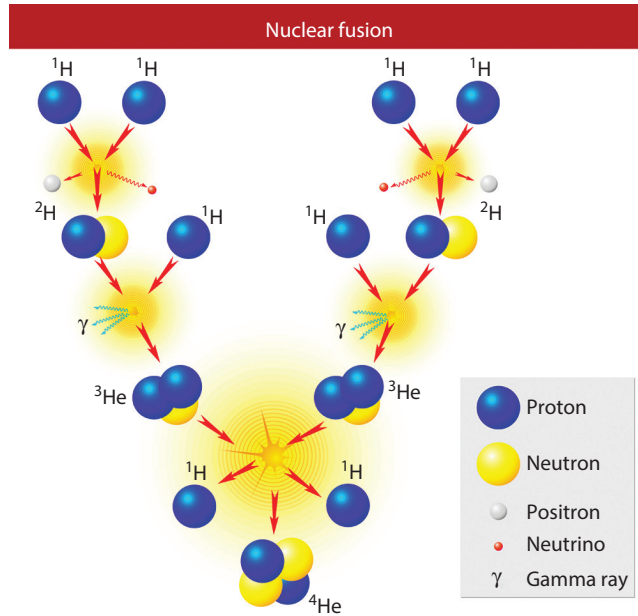


Figure F.75 Solar proton fusion diagram.

Fusion, heat of

[thermodynamics] The ENERGY transfer (i.e., heat Q) in the process of converting one PHASE of a medium into another, measured per unit mass (m): $h_L = Q/m$. The LATENT HEAT of FUSION specifically refers to the SOLIDIFICATION or melting (liquefying) of a FLUID and solid, respectively.

Fusion reactor

[atomic] Based on the ENERGY release for FUSION, artificial fusion between deuterium (${}^2_1\text{D}$) and tritium (${}^3_1\text{T}$) particles is used to generate energy and from hence ELECTRICITY in fusion power plants. The fusion processes as follows: ${}^2_1\text{D} + {}^2_1\text{D} \rightarrow {}^3_2\text{He} + {}^1_0\text{n} + 3.3 \text{ MeV}$, releasing a NEUTRON (${}^1_0\text{n}$); alternatively, ${}^2_1\text{D} + {}^3_1\text{T} \rightarrow {}^4_2\text{He} + {}^1_1\text{H} + 4.0 \text{ MeV}$, releasing a PROTON (${}^1_1\text{H}$). Additional follow-up reactions are ${}^2_1\text{D} + {}^3_2\text{He} \rightarrow {}^4_2\text{He} + {}^1_1\text{H} + 18.3 \text{ MeV}$ and ${}^2_1\text{D} + {}^3_1\text{T} \rightarrow {}^4_2\text{He} + {}^1_0\text{n} + 17.6 \text{ MeV}$; the final process has the largest CROSS SECTION. (Note: $1 \text{ MeV} = 1.602176565 \times 10^{-13} \text{ J}$.) The fusion process needs to be fueled by collision, requiring a PARTICLE ACCELERATOR. No functioning FUSION REACTOR are commercially operational at this time (also see FISSION REACTOR).



g

[general] Acceleration due to GRAVITY (*also see* GRAVITATIONAL ACCELERATION) (see [Figure G.1](#)).

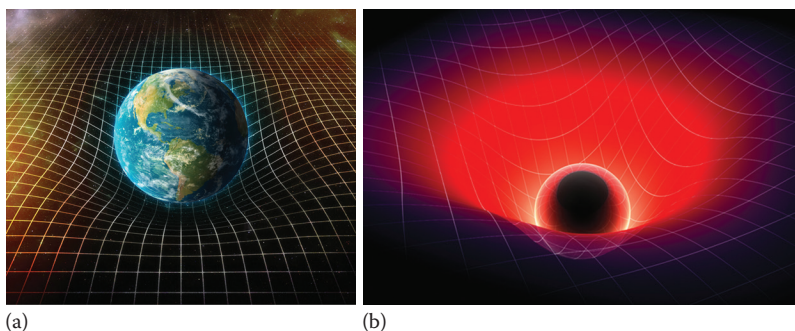


Figure G.1 (a) How space may be considered a sheet where the planets form indentations that are a function of their “gravitational acceleration” (i.e., mass/weight), where particles and photons flow through space as if they roll over the surface of the sheet, being drawn closer to the indentation left by the planets and other celestial bodies due to the incline of the “surface of space” in proximity to the planet/star/galaxy, and so on (galactic phenomena are bending space). (b) A black hole in this case would leave a massive through where all photons, passing objects, and stationary object that are coming on the incline as the indentation in space becomes deeper with the ever growing black hole (including planets) are falling into.

Gabor, Dennis (1900–1979)

[computational, general, optics] A physicist and electrical engineer from Hungary. Dennis Gabor is generally considered to be the “inventor” of HOLOGRAPHY, storing three-dimensional data in a

two-dimensional matrix, approximately in 1948. He received the Nobel Prize in Physics for his development of the holographic method in 1971 (see [Figure G.2](#)).



Figure G.2 Dennis Gabor (1900–1979).

Gadolinium oxysulfide ($\text{Gd}_2\text{O}_2\text{S}$)

[biomedical] An inorganic chemical molecular assembly. The compound $\text{Gd}_2\text{O}_2\text{S}$ is known for its attenuation spectrum of X-ray RADIATION. The x-ray attenuation is used for dosimetry purposes in RADIATION THERAPY. The attenuation (μ_{att}) in the keV to MeV photon ENERGY range is expressed as the mass attenuation coefficient μ_{att}/ρ , where ρ is the density, or as the mass-energy attenuation μ_{en}/ρ .

Gait

[biomedical, mechanics] The step rate of a person walking, specifically any deviations from a continuous step sequence. Additional gait-related phenomena are in the difference between the step format of the right and the left LEG, where one foot may be dragging, however not continuously. The gait can be a very discreet phenomenon, which may be difficult to analyze with conventional SIGNAL processing

methods. One mechanism of automated computer-based investigation may involve the use of wavelet analysis (see [Figure G.3](#)).



Figure G.3 Snapshot of walking gait.

Gait cycle

[biomedical, computational, mechanics] The MOTION of the foot during walking: (1) making contact with floor, (2) foot rests (ankle bends), (3) LIFT, and (4) swing.

Galaxy

[general] Grouping of stars and planets. The affirmation by EDWIN HUBBLE (1889–1953) in 1924 for the cluster of stars at close proximity to our SOLAR SYSTEM (approximately 2×10^6 light-years DISTANCE) formed a scientific description of a neighboring GALAXY, not merely a grouping of stars. The Andromeda nebula discovery by Hubble opened a new dimension to galactic exploration. Further exploration proved that the solar system is part of a galactic formation, named the MILKY WAY. The Milky Way has an approximate CROSS SECTION of 6×10^4 light-years. This size appears average for a galaxy. The Splinter Galaxy (NGC 5907 or “Knife Edge”) is a spiral galaxy discovered by WILLIAM HERSCHEL (1738–1822) in 1788 and is at approximately 5×10^7 light-years from our solar system and has a diameter of 2×10^5 light-years. The Splinter Galaxy is located in the constellation Draco. Galaxies also form attractive bonds and make

groupings of their own. One specific example is the Wild's triplet, a grouping of three galaxies that has connecting gravitational bridges, apparently spanning millions of light-years (see [Figure G.4](#)).

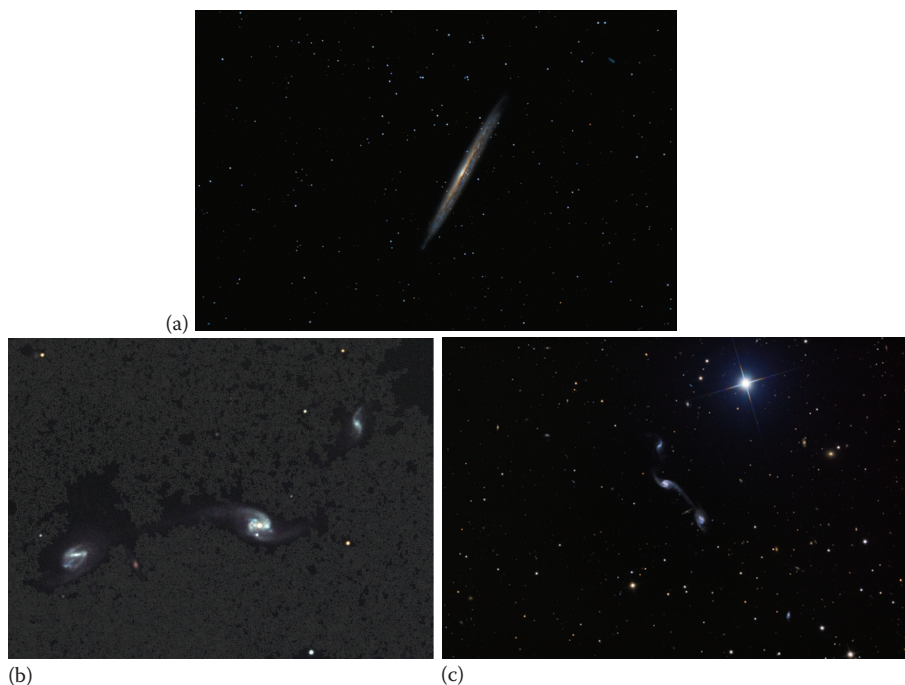


Figure G.4 (a) Splinter Galaxy; NGC 5907, a spiral galaxy located approximately 50 million light-years from Earth. (Courtesy of Stefano Campani.) (b and c) Wild's triplet, three galaxies in three-dimensional arrangement at almost perfect $4\pi/3$ solid angle interval, contorted locking geometry. (Courtesy of Adam Block, Caelum Observatory.)

Gale, Henry Gordon (1874–1942)

[general, optics] A physicist from the United States. In 1908, Henry Gale postulated the concept of accelerating charges (the elusive electrons that still were only the hypothetical building blocks of MATTER) causing the emission of ELECTROMAGNETIC RADIATION, next to the SCATTERING of light by (charged) particles with contemporary ROBERT ANDREWS MILLIKAN (1868–1953). The energetic content of the PHOTON was not fully established until 1915, by Robert Millikan (reluctantly, and still defiant of the

postulations made by ALBERT EINSTEIN [1879–1955] in 1905 [see PHOTOELECTRIC EFFECT]), after Millikan verified the existence of the electron in 1909 and quantified the charge (see Figure G.5).



Figure G.5 1899 picture of Henry Gordon Gale (1874–1942). (Courtesy of University of Chicago Photographic Archive, [apf digital item number: apf1-06260], Special Collections Research Center, University of Chicago Library, Chicago, IL.)

Galenus, Claudius (c. 130–201)

[biomedical, optics] (*also* Galen of Pergamum or Galen) A Greek anatomist, physiologist, and physician. Galen followed the lead of Plato (427–347 BC) on VISION and EXTRAMISSIION; the EYE emits rays to probe the environment. Although misconceived about the vision phenomenon, Galen researched and described the eye in great detail in various publications, also describing the link between the eye and the brain. Galen defined the optic nerve as the “pneuma” in his publications. Galen practiced MEDICINE in The Roman Empire. While treating gladiators, he was offered a glimpse into the HUMAN BODY. He also educated himself with anatomical dissections on pigs and monkeys, due to the fact that vivisection was prohibited under Roman law.

Galerkin method

[computational, fluid dynamics] A method used in finite ELEMENT calculations.

Galilean transformation

[computational, mechanics] The MOTION of a PARTICLE can be observed from several different reference frames simultaneously, each with their respective coordinate systems. Various coordinate transforms are in use; in the Galilean transform, the primary assumption is that the origin of two coordinate systems coincides at time $t = 0$, while the second coordinate system (S') is moving at constant VELOCITY (v^*) with respect to the first reference frame (S). The time frames for observers in both coordinate systems are identical $t = t'$. Assuming motion in the x -direction gives the transform $x' = x + v^*t$, $y = y'$, and $z = z'$ in CARTESIAN COORDINATES. Using the standard differentiation to obtain velocity ($v_i = dx_i/dt$) and acceleration ($a_i = dv_i/dt$), this yields $v_x = v'_x + v^*$, $a_x = a'_x$; $v_y = v'_y$, $a_y = a'_y$; and $v_z = v'_z$, $a_z = a'_z$.

Galilean–Newtonian relativity

[atomic, nuclear] A relativistic theory under the assumption that all observers move with a constant velocity with respect to each other, under “general relativity.” All objects have the exact same absolute values and parameters (i.e., Newtonian bodies) for all respective observers. This will make the objects indistinguishable. This reference frame is also referred to as “inertial.” Galilean–Newtonian relativity has a strict rule of SIMULTANEITY and absolute objects. The main transition is the introduction of the concept of light CONES versus straight-line propagation (linear for all phenomena and objects under Newtonian principles). The light cone introduces a PROBABILITY aspect, whereas Galilean and Newtonian MOTION and phenomena are well demarcated and linear. The general relativistic approach of gravitational influences still holds, for instance, the existence of GRAVITATIONAL WAVES can be made to adhere, but will generally fall outside the realm. Galileo made it clear that GRAVITATION has the same value for all objects and phenomena. ALBERT EINSTEIN (1879–1955) “unified” the gravitational influences to include that there are no free bodies in the UNIVERSE, all particles experience gravitational attraction, both on small and large scale (see DILATION OF TIME).

G

Galilei, Galileo (1564–1642)

[general, thermodynamics] Galileo Galilei Linceo, an Italian scientist and founding father of the modern PHYSICS concepts. Galilei first studied MEDICINE and followed with physics and mathematics, inspired by his father (Vincenzo Galilei [1533–1591]) who was a musical artist with scientific tendencies. Galilei performed many experimental observations of concepts that were *a priori* postulated under the school of ARISTOTLE (384–322 BC). His first contributions were in the validation of the concept of GRAVITATION acceleration (his works on the laws of free fall: *Sermones de Motu Gravium*), specifically illustrated by dropping objects from the Tower of Pisa, his place of birth. As an astronomer, he obtained fame in 1609 with his observations made using the TELESCOPE developed by HANS LIPPERHEY (1570–1619) to describe relief on the surface on the MOON with calculated altitude from the shadow cast by solar illumination. Presumably, Galileo made improvements to the telescope by introducing double tubes for improved focusing around 1610. His observations of VENUS made a firm believer out of him of the teachings by NICOLAUS COPERNICUS (1473–1543). Additional work of Galileo was in the determination of the speed of light. The first recorded use of a THERMOMETER can also be attributed to Galilei. In approximately 1595, Galilei provided a mechanism to measure temperature using the THERMAL EXPANSION of AIR, using a GLASS bulb with a narrow (almost CAPILLARY) downward tubular extension to use different levels of VACUUM to draw-in water from an open reservoir, using the level of the water as an indication of temperature. Due to his conflict with the Catholic Church and in particular the inquisition, he fell out of grace and was incarcerated in the dungeons of the ruler of Rome in 1633 and had to denounce his following of Copernicus. The persecution was primarily based on his work “*Dialogo sopra i due sistemi del monde*” (1632) that was banned and not released until 1822. He was placed on house arrest in 1636. His masterpiece “*Discorse e Dimonstrazioni*” (1638, Leiden, the Netherlands) described in detail the laws of gravitation and kinematic and momentum as well as the

structure and forces on solid media. Most of Galileo's work was not published in Italy but transported to the Netherlands to avoid conflicts with the Catholic Church (see [Figure G.6](#)).

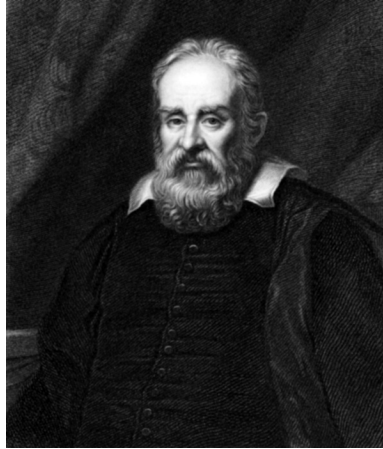


Figure G.6 Galileo Galilei (1564–1642). (Courtesy of R. Hart.)

Galilei, Galileo, acceleration experiments

[general] GALILEO GALILEI (1564–1642) postulated that all objects accelerate with the same absolute acceleration but did not have the equipment to measure the duration and velocity during direct vertical fall accurately enough. To compensate for the lack of RESOLUTION in the equipment, he changed the experiment to rolling objects, at different ANGLES of incline and for various masses. The extrapolation to a total vertical drop provided him with proof of a universal absolute GRAVITATIONAL ACCELERATION.

Galilei, Galileo, law of inertia

[general] GALILEO GALILEI (1564–1642), in his experimental design for testing absolute GRAVITATIONAL ACCELERATION, allowed the balls to roll down a curved ramp and subsequently up a curved ramp. The ball never reached the same height as from which it was released, and he concluded that FRICTION must convert a portion of the momentum. He assumed that a frictionless rolling ball would perform a pendulum MOTION on a symmetric ramp for infinity. These observations led

SIR ISAAC NEWTON (1642–1727) to his first law “the LAW OF INERTIA” (see [Figure G.7](#)). (Note that Isaac Newton was born within a year after Galileo’s death.)



Figure G.7 Galileo Galilei’s (1564–1642) law of inertia, the bicycle will not reach higher than the point from which it took off, assuming the person is not paddling.

Galilei, Galileo, pendulum

[general] GALILEO GALILEI (1564–1642) in 1581 observed that a candelabrum in the cathedral in Pisa was pulled and released to reveal a swing MOTION that appeared to have a steady constant rhythm, the period of the swing. He supposedly used his HEART beat as a time-keeping mechanism, because (stop-) watches were not available, only “hour” time pieces. Galilei was studying MEDICINE at the time and the use of his pulse beat may have been an obvious choice (order of SECOND [s]). The period (T) of a PENDULUM is directly proportional to the square root of the length of the pendulum (ℓ) and is independent of the mass attached, for relatively small angular displacement $T \approx 2\pi\sqrt{\ell/g}$, where g is the GRAVITATIONAL ACCELERATION (see [Figure G.8](#)).

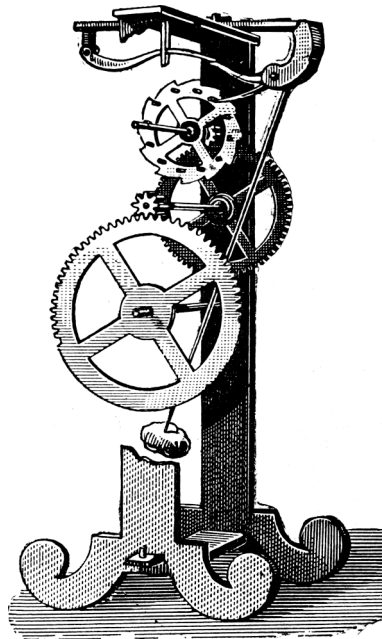


Figure G.8 Pendulum design by Galileo Galilei (1564–1642).

Galilei, Galileo, thermoscope

[general, thermodynamics] A bulb attached to a GLASS pipette invented by GALILEO GALILEI (1564–1642) is held upside down in a reservoir of LIQUID and the bulb on top will expand the GAS or contract in gaseous volume, displacing the liquid in the CAPILLARY tube as function of temperature at the top bulb. The THERMOSCOPE did not have a scale and was used in relative QUANTIFICATION only. The thermoscope was converted to a THERMOMETER by a French physician J. Rey in 1631 by placing the bulb on the bottom and allowing the liquid to expand up the narrow glass tube and placed marking on the tube for absolute values. Not long after this the water or wine was replaced by mercury or high-concentration ALCOHOL (see [Figure G.9](#)).



Figure G.9 Operation of the thermoscope.

Galilei transformation

[mechanics] See GALILEO TRANSFORMATION.

Galileo number ($Ga = gD^3\rho^2/\eta_{\text{kin}}^2$)

[fluid dynamics] A dimensionless number pertaining to viscous FLUID flow representing the ratio of the REYNOLDS NUMBER multiplied times the gravitational force over the resultant viscous forces, with g the GRAVITATIONAL ACCELERATION, D the characteristic diameter of the FLOW, ρ the density of the fluid, and η_{kin} the KINEMATIC VISCOSITY. The Galileo number is used in viscous flow as well as general flow to scale events in momentum and HEAT TRANSFER (e.g., MIXING/convection/CIRCULATION) and related to THERMAL EXPANSION in particular. The number is dedicated to the efforts by the Italian scientist GALILEO GALILEI (1564–1642).

Galileo transformation

[atomic, mechanics] When two observation reference frames (S, S' , respectively) are moving with respect to one and another (with relative velocity $\vec{U} = (u, v, w)$), the observation (can be stationary but changing in place ($\vec{x} = (x, y, z)$) or MOTION) seen from one reference frame can be transformed to the other reference frame by using the relative VELOCITY ($\vec{v} = v_x, v_y, v_z$), using the standard equation for location. This provides the location transformation as $x = x' + ut$; $y = y'$; and $z = z'$, while time is constant $t = t'$. The velocity

transformation is now $v_x = v'_x + u$; $v_y = v'_y$; and $v_z = v'_z$, while for the acceleration this yields $a_x = a'_x$; $a_y = a'_y$; and $a_z = a'_z$. Sometimes it is also referenced as Galileo–Newton transformation equations.

Gallium ($^{70}_{31}\text{Ga}$)

[general] A semiconductor material ELEMENT used in many transistor and DIODE arrangements to achieve the p – n configuration. Gallium was discovered in 1875 by a French chemist PAUL-ÉMILE LECOQ DE BOISBAUDRAN (1838–1912) and predicted in 1871 by a Russian chemist DMITRI IVANOVICH MENDELEEV (1834–1907).

Galvani, Luigi (1737–1789)

[general] An Italian physicist and scientist, contemporary of and collaborator with Count ALESSANDRO VOLTA (1745–1827). The combined efforts of the invention of the VOLTAIC PILE by Galvani and the theoretical and experimental work of Volta on capacitance led to the definition of the ELECTRIC BATTERY by Volta in 1780 (see [Figure G.10](#)).



Figure G.10 Statue erected in honor of Luigi Galvani (1737–1789).

Galvanic mechanism

[electromagnetism, general, thermodynamics] The deflection of a current-carrying conducting ELEMENT (including semiconductor) under the influence of a MAGNETIC FIELD (generally the Lorentz force). The magnetic field results from a current density and generates a Hall effect next to a temperature gradient in perpendicular to the magnetic field direction as well as the direction of the current. Additional phenomena include the induction of magnetoresistance as well as in fourth place the Nernst effect, which is a thermal gradient in the direction of the current (see [Figure G.11](#)).

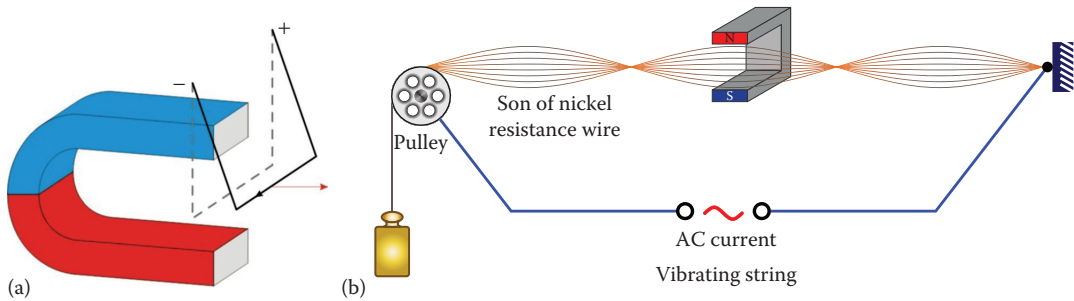


Figure G.11 Force on a current under the Galvanic mechanism: (a) direct current (DC) and (b) alternating current (AC).

Galvanometer

[electromagnetism, general] A device to measure current (I), resulting from a potential difference, using a conducting coil, which is suspended between the NORTH and south POLES of two respective permanent magnets. The MAGNETIC FIELD between the poles ($\vec{B}$) interacting with the current produces a force, generating a torque on the axis that is attached to the coil, that will force the coil to rotate. The force is $\vec{F}_m = \int_{\text{wire}} I d\vec{\ell} \times \vec{B}$ (i.e., Lorentz force), where ℓ is length (and direction; coil) of the wire segment containing the charges in MOTION. Placing an (infinitely) high RESISTOR in series with the galvanometer converts the current meter into a VOLTMETER (see [Figure G.12](#)).

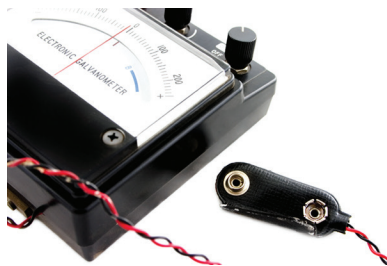


Figure G.12 Galvanometer.

Gamma absorption

[nuclear] Gamma RADIATION is an ELECTROMAGNETIC RADIATION that has a greater likelihood of being absorbed in heavy ELEMENTS (i.e., high atomic number), mostly dense media. The attenuation follows the Beer's law of attenuation. Since gamma radiation is mass less and free of charge and has a very short wavelength, it is difficult to block but on an atomic level will not cause nuclear transmutations. The penetration is topped by NEUTRON rays; however, alpha and beta rays will be quenched much earlier. Gamma rays can be detected by a GEIGER COUNTER.

Gamma curve

[acoustics, computational, optics] A correction mechanism used in IMAGE processing defined by the POWER LAW correlating the incident radiance/signal intensity (V_{in}) to the outgoing radiance/signal intensity (V_{out}) expressed as $V_{out} = \mathcal{A}V_{in}^{\gamma^*}$, where $\mathcal{A}$ represents the “efficiency” and γ^* represents the “encoding gamma.”

Gamma decay (γ)

[general, nuclear] Nuclear degradation from an excited state releases high-energy photons with ENERGY ranging from keV to MeV. An example of gamma DECAY is in the degradation of URANIUM (^{238}U) when colliding with a NEUTRON (1_0n), yielding an excited-state NUCLEUS $^{239}\text{U}^*$ further decaying as $^{238}\text{U} + ^1_0n \rightarrow ^{239}\text{U}^* \rightarrow ^{239}\text{U} + \gamma$. In positron emission TOMOGRAPHY specifically, a free positron will virtually immediately annihilate with any of the many free electrons in the residing medium. The annihilation process releases a substantial amount of energy: greater than 1 MeV. This energy is released as two gamma QUANTA with 511 keV emitted in perfectly perpendicular direct to each other. The energy balance for the POSITRON ANNIHILATION process and the gamma pair production is described in the following equation (see Figure G.13):

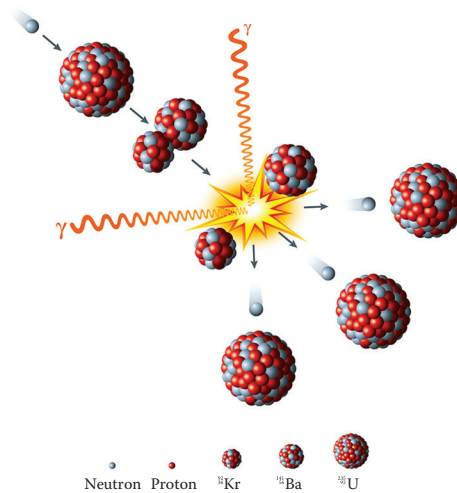


Figure G.13 Gamma decay for the fission process of uranium.

$$E_{\text{pos}} + E^{\text{kinetic}} + E_e \geq 2E_\gamma$$

The rest energy is determined by the difference in energy of the ISOTOPE and the product. In addition to the rest energy of the positron (E_{pos}) and the electron (E_e), respectively, there may be additional kinetic energy involved from positron or electron MOTION E^{kinetic} . The nuclear energy follows from the quantum PHYSICS theorem that mass and energy are equivalent, providing the rest MASS ENERGY equivalent as illustrated by equation $E = mc^2$, where E represents the rest energy of the ELEMENT, m is the atomic mass, and c is the speed of light. Substitution of equation $E = mc^2$ into $E_{\text{pos}} + E^{\text{kinetic}} + E_e \geq 2E_\gamma$ and using the PHOTON energy $E = h\nu$ yields $m_{\text{pos}}c^2 + m_e c^2 = 2h\nu_\gamma$. Filling in the mass-equivalent energy for each component yields the energies in equation $511 \text{ keV} + E_{\text{pos}}^{\text{kinetic}} + 511 \text{ keV} \geq 1.022 \text{ MeV}$.

Gamma decay, classification of

[nuclear] Gamma RADIATION is classified based on the QUANTUM principles, in particular the angular momentum of the NUCLEUS (J) prior to emission and post-emission and the angular momentum of the emitted PHOTON (ℓ) need to satisfy $J_{\text{initial}} = J_{\text{final}} + \ell$ (see Figure G.14).

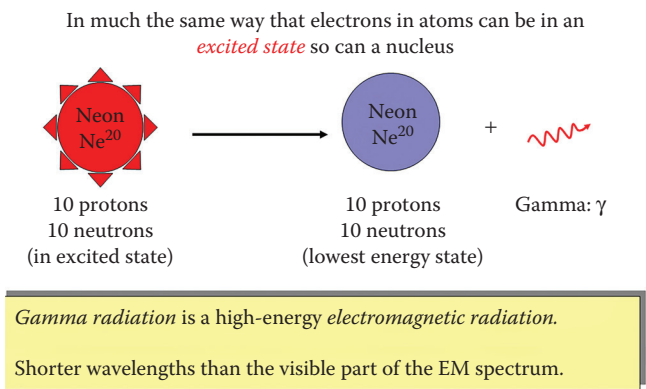


Figure G.14 Gamma (λ) decay process.

Gamma decay, hindrance factor (f_v)

[nuclear] The limitation on the POLARIZATION of gamma emission with respect to restricted nuclear transitions, which appears to be linked with MACROSCOPIC resonance effects and is defined as $f_v = (\tau_{1/2} / \tau_{\text{Weiss}})^{1/\nu}$, where $\tau_{1/2}$ is the measured half-life of the nuclear transition and τ_{Weiss} is the WEISSKOPF HALF-LIFE.

Gamma decay, Mössbauer effect

[nuclear] See MÖSSBAUER EFFECT.

Gamma decay, Weisskopf estimate of decay constant

[nuclear] See WEISSKOPF HALF-LIFE, derived by VICTOR WEISSKOPF (1908–2002) (see also RADIOACTIVE DECAY).

Gamma particle

[biomedical, electromagnetism, nuclear] A PHOTON, an electromagnetic WAVE, sometimes found in literature based on historic circumstances (see GAMMA RAY) (see Figure G.15).

Radiation; effective mass

Particle	Mass* (MeV/c ²)	Charge
Gamma (γ)	0	0
Beta (β)	~0.5	–1
Alpha (α)	~3752	+2

$*m = E/c^2$

Figure G.15 Comparison of radioactive decay products with respect to effective mass.

Gamma ray

[nuclear] High-frequency ELECTROMAGNETIC RADIATION with wavelength generally shorter than X-RAY (however, an overlap is found depending on the reference), ranging from $\lambda = 10^{-10} \text{ m} = 0.1 \text{ nm}$ to $\lambda = 10^{-14} \text{ m} = 10^{-5} \text{ nm}$, emitted from the NUCLEUS. Gamma rays are emitted from nuclear degradation, whereas x-ray RADIATION generally originates from ELECTRON DECAY. The nomenclature dates back to the early days of RADIOACTIVITY, late 1800s (*also see* GAMMA DECAY).

Gamma ray burst

[astronomy/astrophysics, electromagnetism] Short bursts of gamma radiation with ENERGY ranging from $\sim 20 \text{ keV} \leftrightarrow > 10 \text{ GeV}$ with a measured random duration between $10 \text{ ms} \leftrightarrow > 1000 \text{ s}$. The RADIATION is associated with unidentified astronomical events and seemingly never originate from the same galactic location. The detection coincides with investigations of global nuclear ACTIVITY (e.g., test discharge of atomic bombs) by the military SATELLITE Vela.

G

Gamow, Georgiy Antonovich (George) (1904–1968)

[atomic, nuclear] A scientist and physicist from then Russian Empire (also USSR/Soviet Union—now Ukraine). Gamow's main contributions were in the description of alpha-decay principles and the origins to the source of ENERGY in the UNIVERSE. His work in ASTROPHYSICS has contributed to the formulation of the "BIG BANG" THEORY, as initiated by ALEXANDER FRIEDMANN (1888–1925). Gamow also stated in 1930s that the volume of a NUCLEON in an ATOM remains constant with increasing atomic number A . The theoretical work of George Gamow (sometimes found as "Gamov") quantitatively describes the alpha-decay "QUANTUM TUNNELING" process and mechanism of action (see [Figure G.16](#)).



Figure G.16 Georgiy Antonovich Gamow (George) (1904–1968) (Cyrillic, Russian: Георгий Анто́нович Га́мов) in 1930.

Gamow–Teller decay

[atomic, general, nuclear, solid-state] Nuclear transition where one unit of angular momentum is relinquished by the emission of a pair of leptons (e.g., electron or NEUTRINO), hence changing the nuclear SPIN and associated angular momentum QUANTUM NUMBER by 0 or 1 $S_{\beta} = 0, 1$. In comparison, a Fermi transition only takes place without a change in angular momentum.

Ganguillet–Kutter equation

[fluid dynamics] Heuristic flow-dynamics equation developed in 1869 by the Swiss engineers Emile-Oscar Ganguillet (1818–1894) and Rudolph Kutter (1818–1888). The equation was based on their observations of the river flow in the Swiss mountains, providing an OPEN CHANNEL in comparison to tube flow. The Ganguillet–Kutter equation approximates “Chézy’s C_{chezy} ” with respect to the FLOW resistance in a channel, specifically with respect to the bottom SURFACE ROUGHNESS (N) as $\eta_{\text{GK}} = 1/C_{\text{chezy}} = [1 + [a + (m/s)](N/\sqrt{R})]/[a + (b/N) + (m/s)]$, where a , b , and m are constants, s the slope of the bank, and R is the mean radius of curvature of the flow-bed trough.

Gap junction

[biomedical, chemistry, thermodynamics] In the MEMBRANE of cardiac cells (i.e., HEART MUSCLE) there are ION passages with a diameter of about 1.6 nm, connecting cardiac cells for chemical communication while remaining electrically insulated from the extracellular space. The gap-junction channels have a low RESISTANCE and control the FLOW of ions by means of fixed anions that will regulate the incoming ions based on their size and electro negativity. These channels are complementary to another form of transmembrane ion transport: ION CHANNELS (see Figure G.17).

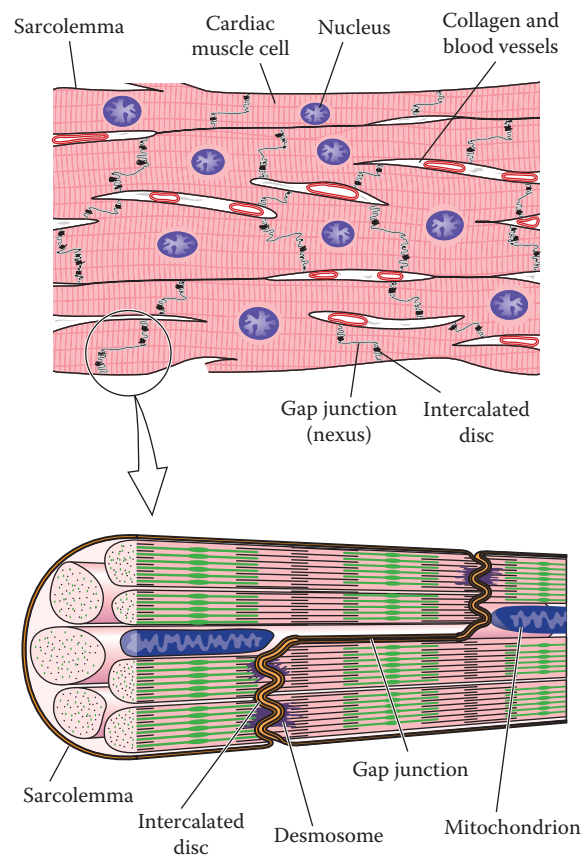


Figure G.17 Gap junction in ion transfer for the cardiac muscle.

Gas

[biomedical, fluid dynamics, general, geophysics] A material PHASE with lower density than solid or LIQUID found to exist above the VAPOR point, or alternatively the TRIPLE POINT. The GAS PHASE of water is water vapor above $100^{\circ}\text{C} = 372.16\text{ K}$ under normal pressure (at sea level), and oxygen is in gas phase above 90.2 K . Definition of “gas” was developed by the alchemist JOHANNES BAPTISTA VAN HELMONT (1579–1644) from the Netherlands in approximately 1620, at the time presumably derived from the Greek word for “gap” or “gaping void”: Khaos ($\chi\alpha\omicron\varsigma$). In Greek mythology, Khaos (pronounced “Chaos”) is the goddess of AIR. Gas is also considered an AEROSOL. Certain ELEMENTS and molecular structures in gas format obey the IDEAL GAS LAW. A gas generally obey the Gay-Lussac law $PV = nRT$, where P is the pressure of the gas (in Pascal: $\text{Pa} = \text{N/m}^2$), V is the volume (m^3), n is the number of moles of the medium, $R = 8.3144621(75)\text{ J/Kmol}$ is the gas constant, and T is the temperature (in Kelvin).

Gas, elasticity of

[fluid dynamics] In deviation from an IDEAL GAS, the collisions will no longer be perfectly elastic, resulting in a deformation in the DENSITY (ρ)–PRESSURE (P) relationship with respect to an isothermal situation described by $P/P_0 = \rho/\rho_0$, yielding $\rho/\rho_0 = 1 + (P/\kappa_{\text{elast}})$, with κ_{elast} the ELASTICITY of the volume of gas.

Gas, ideal

[fluid dynamics, general] Collisions between the ions, atoms, or molecules are perfectly elastic and the IDEAL GAS LAW applied within a range of pressure and temperature domains. VAPOR is most often unstable and cannot be considered an IDEAL GAS close to the TRIPLE POINT or the vapor point. An ideal gas is a gas that has no imminent condensation potential and the intermolecular collisions are perfectly elastic. The ideal gas obeys the gas law within a certain range of perturbations of the boundary conditions.

Gas, molecule speed in

[general] An IDEAL GAS at a certain TEMPERATURE (T) will have totally elastic interaction in collisions and the absolute value of the (average) VELOCITY ($\bar{v}$) will be maintained based on the kinetic ENERGY $\bar{v} = 0.92v_{\text{rms}} = \sqrt{3\kappa_B T/m} \xrightarrow{\text{lim mass} \rightarrow \text{small}} \sim 3(P/\rho)$, where $\kappa_B = 1.3806488 \times 10^{-23}\text{ m}^2\text{kg/s}^2\text{K}$ is the Boltzmann constant, and m is the molecular mass for a single component gas, P is the pressure, and ρ is the density of the gas. The full speed distribution for the constituents of a gas is described by the Maxwell–Boltzmann speed distribution.

Gas, Newton’s experiments on

[general, mechanics] ISAAC NEWTON (1642–1727) illustrated the compressibility of gasses and the analogy with the Hook’s law and this also related to NEWTON’S THIRD LAW.

Gas, viscosity of

[fluid dynamics] Generally, a GAS is frictionless; however, in order to offer a description for non-ideal gasses, the following equation relates the mean PRESSURE ($\bar{P}$) to the DENSITY (ρ) with respect to an ABSOLUTE TEMPERATURE (Θ) and assign an assumed VISCOSITY (η_{gas}) and a collective of constants ($a + b + c$) that is linked to the internal ENERGY and the rate of deformation ($a + b + c = (1/\rho)(DP/Dt)$) of a volume ELEMENT $\bar{P} = R^* \rho^{\Theta} - \eta_{\text{gas}}(a + b + c)$, where R^* is a constant that describes the nature of the gas as deviating from ideal. For an ideal gas $\eta_{\text{gas}} = 0$.

Gas chromatograph

[electronics, general, solid-state] An analytical device to assist in the analysis of the composition of media in a process called CHROMATOGRAPHY. The analysis of, for instance, fats and oils can quantify the estimated chain

length associated with the fatty-ACID chain, as well as the amount of unsaturation. It is also defined as GAS–liquid CHROMATOGRAPH or liquid–GAS CHROMATOGRAPH (*see* CHROMATOGRAPH) (*see* Figure G.18).

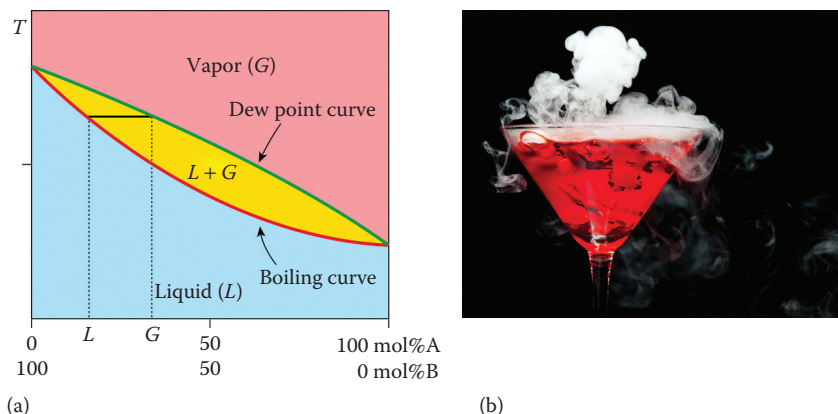


Figure G.18 Gas balance with liquid phase: (a) coexistence of liquid and vapor phase and (b) phase diagram referring to the phase transitions between solid, liquid, and gas, respectively.

Gas constant (R)

[thermodynamics] A constant used in the Gay-Lussac law to link the pressure, volume, and temperature to the respective molar content of the constituents of a gaseous substance $R = 8.3144621(75) \text{ J/Kmol}$. It is also described as the universal gas constant. Based on the empirical work by ROBERT BOYLE (1627–1691) and JACQUES CHARLES (1746–1823), where Boyle described the fact that a constant amount (i.e., moles; n with $N = nN_A$ the number of molecules, and Avogadro's number $N_A = 6.022137 \times 10^{23} \text{ J/K}$) of gas at a fixed temperature shows a decrease in pressure that is directly proportional to the increase in volume. Charles, on the other hand, linked the pressure in a fixed volume of gas to the temperature expressed on the Kelvin scale.

Gas diffusion

[general] A GAS and LIQUID with the same molecular structure defines VAPOR. When gas or vapor is exposed to a boundary that is semi-permeable or permeable to the molecules of the gas, the molecules will migrate in the direction of the declining partial pressure, that is, the OSMOTIC PRESSURE or when dissolved as a concentration gradient (*see* Figure G.19).

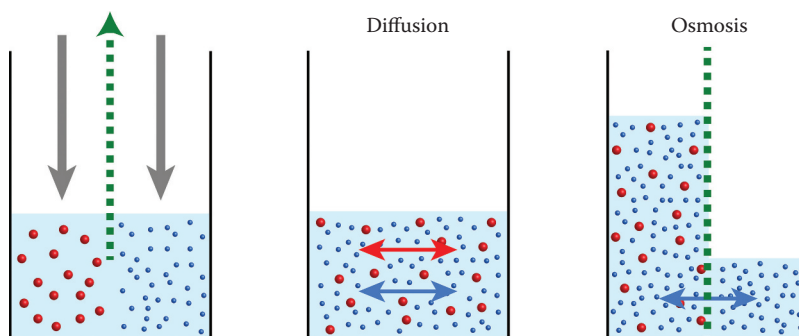


Figure G.19 Diffusion process under partial pressure.

Gas law

[atomic, general] *See* IDEAL GAS LAW.

Gas laws, kinetic theory

[general] PLATO (427–347 BC) already stated that heat and fire result from MOTION; however, the molecular model had not yet been developed. In the sixteenth century, SIR FRANCIS BACON (1561–1626) followed in Plato's footsteps and stated that the essence of heat is motion. This was later refined by JAMES CLERK MAXWELL (1831–1879) and LUDWIG EDUARD BOLTZMANN (1844–1906) in a statistical representation of motion of a collection of "particles."

Gas mixture

[thermodynamics] A blend of several gasses that under ideal conditions behaves as separate gasses, treating each constituent as a component with its own parameters and negligible interaction with other gasses in the same closed container. One example of a GAS mixture is the Gibbs–Dalton mixtures. During MIXING of more than one gas, there will be a change in entropy, which is irreversible, since the gasses cannot be separated without special means and added ENERGY. The conditions of the gas mixture are defined by the Gas laws and can be visually interpreted in PHASE diagrams.

Gas phase

[biomedical, fluid dynamics, general, geophysics] *See* GAS.

Gas pressure (P)

[nuclear] The force per unit area exerted by a single molecular quantity or mixture of various quantities of molecules (n , the number of moles) in a container of a certain volume (V), maintained at a certain temperature (T), defined by the IDEAL GAS LAW ($PV = nRT$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant), or more specifically, the Van der Waals equation ($(P + (n^2a/V^2))(V - nb) = nRT$, where a and b are constants that are specific for the gas in question (*Note:* b represents the volume of the total number of individual molecules, the Avogadro number multiplied by the volume of one single molecule). The pressure is the same on all the walls of the container, when the container is a free-standing device. This is different the LIQUID pressure, which changes with the height (h) of the FLUID column with density ρ , described as $P = \rho gh$, where g is the GRAVITATIONAL ACCELERATION.

Gas pressure, kinetic theory of

[atomic, nuclear] A theoretical description of the mobility of molecules that are in free movement with respect to each other in random MOTION. The MECHANICS of the relative motion is defined as follows with the 5 postulates: (1) inter-particle collisions are perfectly elastic; (2) the constituents exert no attractive or repulsive forces on each other; (3) the individual molecules are points with no volume; (4) the particles

(ions, atoms, molecules) in a GAS traveling in straight-lines obeying Newton's laws; and (5) the temperature is defined by the kinetic ENERGY $KE = 3k_B T/2$, where $k_B = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the BOLTZMANN CONSTANT (see Figure G.20).

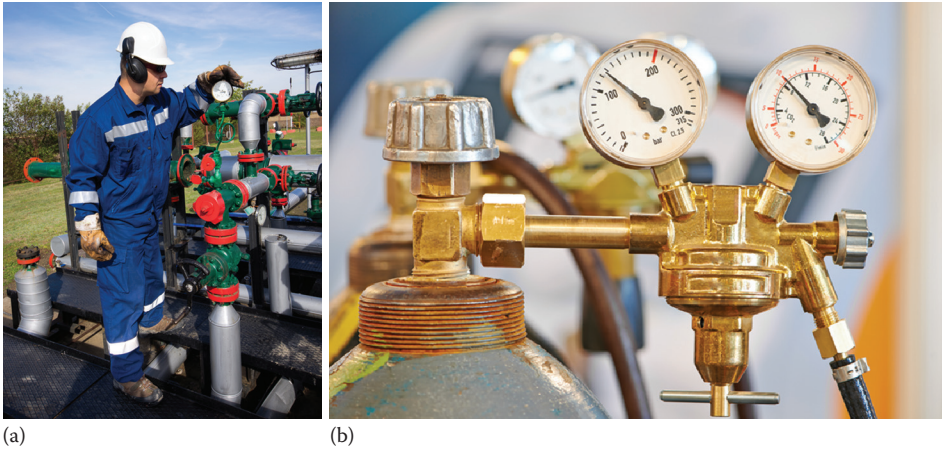


Figure G.20 (a) Gas pressure gauge at natural gas distribution center and (b) gauges on gas tank with compressed gas.

Gas pressure, osmotic (Π_{osm})

[biomedical, chemical, general] The equivalent pressure for the quantity of a mixture of solutes in SOLUTION or suspended in a solid $\Pi_{\text{osm}} = (RT/v_{ii}) \sum_{j \neq i} n_j^*$, where n_j^* represents the molar fraction of species i ($0 \leq n_j^* \leq 1$), $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant, T is the temperature, and v_{ii} is the specific volume per MOLE of SOLUTE. This definition is known as the VAN'T HOFF EQUATION, sometimes also found described under HENRY'S LAW. The OSMOTIC PRESSURE is sometimes attributed to Ernest Starling (1866–1927), represented by the Starling equation or Frank–Starling equation; however, this generally applies to ION/molecular migration due to a gradient in concentration.

Gastrocnemius

[biomedical, mechanics] LEG muscle below the knee which is split from the lower single connection to the soleus MUSCLE, which in-turn is attached to the Achilles tendon and can hence flex the foot while connected to the calcaneus (heel bone). The gastrocnemius forms the main attribute for the calf of the lower leg.

Gastrointestinal tract

[biomedical] Esophagus, stomach, and intestinal conduit where food is digested and absorbed for consumption by the tissue (also found as GI tract and digestive tract). The gastrointestinal tract has muscles for guided and forced transportation that contract in a PERISTALTIC MOTION (see [Figure G.21](#)).

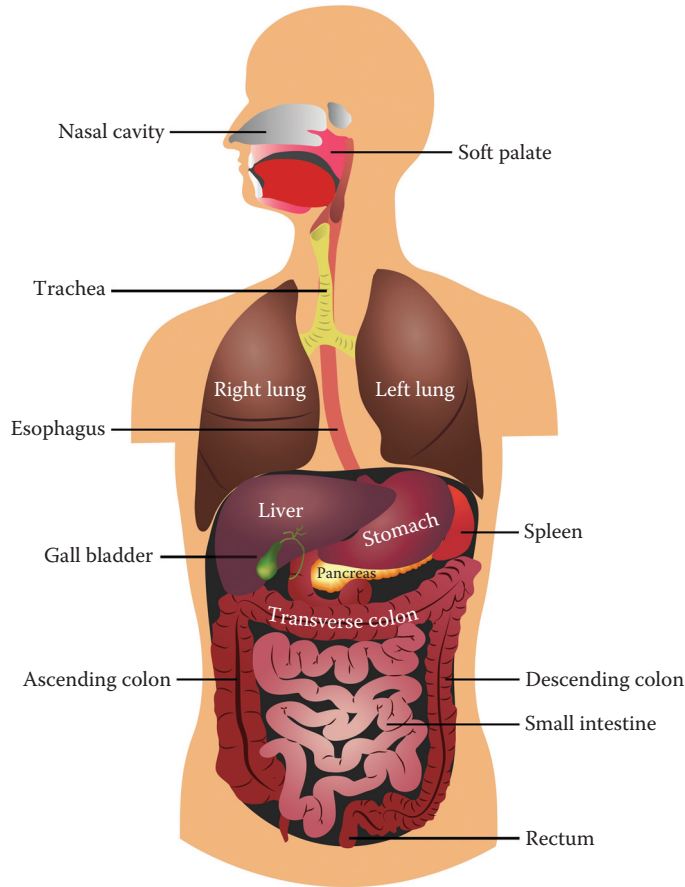


Figure G.21 Diagram of the gastrointestinal tract.

Gate valve

[fluid dynamics] A VALVE mechanism that provides partial to full closure of a FLOW by lowering a wedge or gate in the path of flow (usually a round-tube flow) by means of turning knob attached to a treaded

push-rod turning through a screw hole, which drives the wedge. Other advance mechanisms use a worm wheel attached to a slotted shaft or a magnetic SOLENOID (see [Figure G.22](#)).

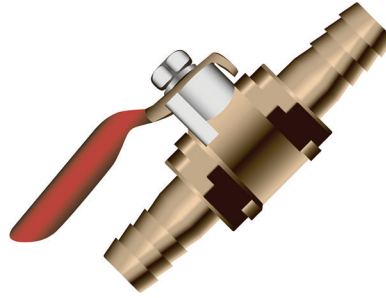


Figure G.22 Gate valve.

Gauge blocks

[general] Verified accurate weight and size blocks used for calibration of instruments, such as a scale. It is usually made of steel to ensure resilience and negligible influences resulting from changing boundary conditions.

Gauge field

[computational, quantum] A mathematical frame of reference in Lagrangian transformations and associated vector fields. Gauge fields are used to describe the elementary forces of nature. Gauge fields are the basis of the Lagrangian. Maxwell's theory of ELECTRODYNAMICS applied the gauge field symmetry implications for the first time. One specific example is in YANG–MILLS FIELD. It is also referred as gauge.

Gauge force field

[general, quantum] A force field between ELEMENTARY PARTICLES that uses a “particulate” connection that is used to transmit the interaction between the fermions, bosons, and quarks. The theory originated in invariant Lagrangian description of field theory is referred as the Lagrangian DEGREES OF FREEDOM. Gauge force field approximation readily found applications in QUANTUM THEORY. The GAUGE THEORY represents the potential for transformations between different potential gauges without influencing the outcome.

Gauge invariant

[computational, electromagnetism, energy, general, thermodynamics] All theories that are proven and accepted are independent of the arbitrary definitions that describe the phenomena and boundary conditions.

Gauge pressure

[fluid dynamics, general] A reference PRESSURE (P) for a system, not necessarily the ATMOSPHERIC pressure. For instance, the gauge pressure for a dam is the pressure at a specific height (z) measured from the bottom of the lake (with total depth h) $P_{\text{gauge}} = \rho g (h - z)$, not accounting for the atmospheric pressure on the surface. In this example, the gauge pressure defines the force exerted on the WALL of the dam.

Gauge symmetry

[computational, electromagnetism, energy, general, thermodynamics] The fact that any physical phenomenon or PHYSICS system that is subjected to a change that results in an observable modification of the reality (e.g., a snow flake is generally unchanged when the flake is rotated 60° , which is repeatable) while the final

outcome of the process or ultimate STATE of the system will not be different from previously observed end results. Additional forms of symmetry are explained by the NOETHER'S PRINCIPLE, which states that for every continuous system there is a symmetry that correlates a corresponding alternate conservation law and for every conservation law there is a continuous symmetry. Due to the fact that the electric field, and hence the electric potential, is tied to the CONSERVATION OF CHARGE, it follows that classical ELECTRODYNAMICS is GAUGE INVARIANT.

Gauge theory

[computational, electromagnetism, energy, general, thermodynamics, quantum] The description of the interaction between ELEMENTARY PARTICLES using QUANTUM FIELD THEORY. The theory assumes a symmetry of interchangeability of the fields exerted on the particles by each other. The gauge theory requires that the fields can be described by gauge force fields and should obey the SCHRÖDINGER EQUATION. A part of theoretical PHYSICS that uses quantum ELECTRODYNAMICS and is used in HIGH-ENERGY PHYSICS. The gauge theory hinges on the postulate that all theories are balanced in a GAUGE SYMMETRY. One confirming factor of the gauge symmetry is the GENERAL THEORY OF RELATIVITY, whereas the idea originates in quantum electrodynamics, which is gauge symmetric in its formulation. One of the key ELEMENTS in the gauge symmetry is that all PHYSICS LAWS are identical to all observers. In gauge theory, it is shown how all REFERENCE FRAMES and units can be converted or “transformed” (see [Figure G.23](#)).

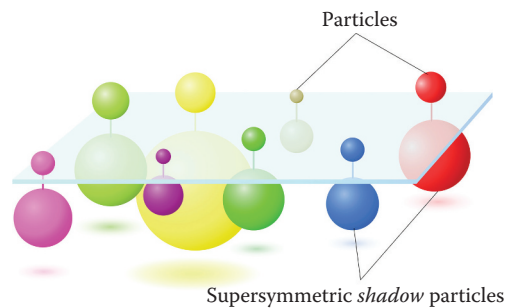


Figure G.23 Supersymmetry as it applies to gauge theory.

Gauss, Johann Carl Friedrich (German: Gauß) (1777–1855)

[biomedical, electronics, general, nuclear] A German scientist, astronomer, physicist, and mathematician. Gauss is most known for his contributions in ELECTROSTATICS and the mechanisms to derive the electric field strength and direction. Gauss contributed significant theoretical descriptions to the field of electrical charge and field theory and electronic interaction. Gauss also introduced the LENS equation relating the object DISTANCE (s_o) to the IMAGE distance (s_i) with respect to the focal length (f_ℓ) of a single lens in 1841 as the GAUSSIAN LENS EQUATION $1/f_\ell = (1/s_o) + (1/s_i)$. The main restriction to the validity of the Gauss' law is the fact that there is a requirement for charge symmetry. Other work of Gauss was in astronomy and

general PHYSICS, specifically OPTICS. Gauss defined the focal length (f) of a single thin lens in 1824 as the reciprocal of the sum of the inverse distance for rays crossing the optical axis (s_0, s_1 , respectively) that emit parallel to the optical axis for both sides of the lens $1/f = (1/s_0) + (1/s_1)$ (see Figure G.24).



Figure G.24 Johann Carl Friedrich Gauss (German: Gauß) (1777–1855), painted by Christian Albrecht Jensen 1887. (Courtesy of Gauß-Gesellschaft Göttingen e. V. [Foto: A. Wittmann] detail from painting by Gottlieb Biermann, 1887.)

Gauss (unit: G)

[biomedical, electronics, general, nuclear] A unit for MAGNETIC FIELD strength, with respect to the Tesla $1T = 10^4 G$.

Gauss law of electrostatics

[electronics, nuclear, solid-state] The electric FLUX (Φ_e) through an arbitrary closed surface enclosing a net total CHARGE (Q) equates the net charge enclosed inside the surface (S) divided by permittivity of VACUUM (ϵ_0): $\Phi_e = Q/\epsilon_0$. It is also found as Gauss' law.

Gauss's law

[biomedical, electromagnetism, electronics, general, thermodynamics] A description of the electric field resulting from any grouping of charges confined by a chosen virtual surface in free space. The expression of the surface integral over this virtual closed surface (encapsulating a volume filled with net charge) of the outward directed electric field MAGNITUDE normal to the surface is proportional to the enclosed net charge. In case the surface of the medium is chosen to follow a specific contorted outline, the electric field line may exit and reenter the volume to exit at a final point on the egress route. The proportionality factor is defined by the reciprocal DIELECTRIC constant of the medium ($1/\epsilon_0$). Gauss's law is an expression that is included in the set of MAXWELL EQUATIONS related to electric and magnetic fields. Two definitions can be distinguished relating to electric and magnetic fields, respectively. For an electric field in VACUUM Gauss's law states that the electric field created by ELECTRIC CHARGES is directly proportional to the magnitude of the charges contained in an enclosed surface, defined as $\oint_S \vec{E} \cdot \vec{n} dA = Q_{in}/\epsilon_0$, where $\vec{E}$ is the electric field, $\vec{n}$ is the normal to the surface A of the enclosed space, Q_{in} is the enclosed net total charge, and ϵ_0 is the dielectric permittivity of vacuum. Analogues for a MAGNETIC FIELD ($\vec{B}$) Gauss's law is defined as $\oint_S \vec{B} \cdot \vec{n} dA = 0$. Gauss's law is part of ELECTROSTATICS. An expression for the total charge (with charge density $\rho(r)$ and a function of location (r)) enclosed within a surface (S) defined by the electric FLUX emerging (Φ_e) from this surface $\int_S \vec{E} \cdot \vec{n} dS = K_{Gauss} \int_V \rho dV$, where the surface has normal unit vectors to the surface $\vec{n}$, the charges generate an electric field defined by Coulomb's law ($\vec{E} = K_{Gauss} (q/4\pi r^2) \vec{r}'$, in direction $\vec{r}'$), $K_{Gauss} = 1/\epsilon_0$, ϵ_0 is the

dielectric permittivity of vacuum, V is the volume enclosed by the surface (S), ρ is the net charge density, and q is the net charge. It is also expressed as $\nabla \cdot \vec{E} = K_{\text{Gauss}} \rho$ (see Figure G.25).

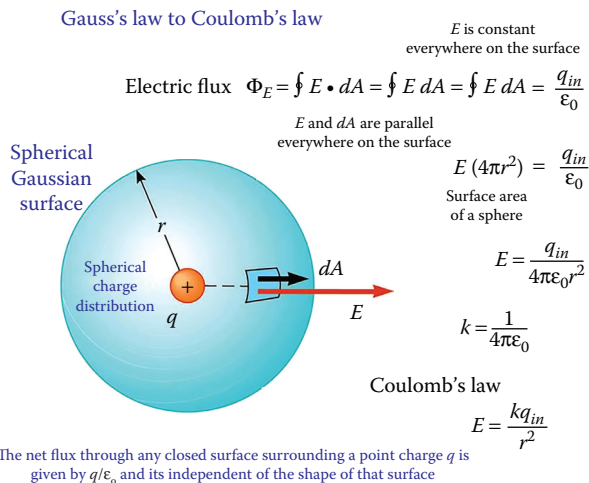


Figure G.25 Illustration how the Coulomb's law and Gauss's law are inter-related.

Gauss's law of electrodynamics

[nuclear] The Maxwell equation in integral form. This applies to a MACROSCOPIC average for a “non-Abelian” GAUGE THEORY analysis, generally electroweak $\int_S \vec{E} \cdot \vec{n} dS = K_c \int_V \rho_e dV$, where $\vec{E}$ represents the electric field, $\vec{n}$ is the normal to the surface (S) holding the charge with volumetric charge density ρ_e for the volume V , K_c is a proportionality constant, which depends on the definition of the system ($K_c = 4\pi$ for a system in Gaussian units and $K_c = 1/\epsilon_0$ with ϵ_0 the DIELECTRIC permittivity of VACUUM).

Gaussian distribution

[atomic, computational] A PROBABILITY density function for events and measured values, also known as the NORMAL DISTRIBUTION $f_{\text{Gauss}}(x) = (1/\sigma_{\text{stat}} \sqrt{2\pi}) \exp[-(21/2\sigma_{\text{stat}}^2)(x - \mu_{\text{stat}})^2]$, where μ_{stat} is the mean value of the observation x and σ_{stat} is the statistical variance. Generally, the VARIANCE (σ_{stat}^2) can be derived as follows: $\sigma_{\text{stat}}^2 = [1/(n-1)] \sum_{i=1}^n (x_i - \mu_{\text{stat}})^2$, with n values.

Gaussian lens equation

[general, optics] An equation relating the object DISTANCE (s_o) to the IMAGE distance (s_i) with respect to the focal length (f_ℓ) of a single LENS as introduced by CARL FRIEDRICH GAUSS (1777–1855) in 1841 as $1/f_\ell = (1/s_o) + (1/s_i)$. An equation relating the image distance (s_i) to the object placement with respect to a lens (s_o) with focal length f : $1/f = (1/s_i) + (1/s_o)$, as derived by CARL FRIEDRICH GAUSS (1777–1855) in 1841.

Gaussian noise

[biomedical, electronics, thermodynamics] Sensor, detector, or imaging NOISE resulting from randomly generated SIGNAL values due to thermal influences or electronic interactions, which describes the mean value ($\bar{x}_i$) as $\bar{x}_i = (1/n) \sum_{i=1}^n x_i$, for a total of n observations of respective values x_i ; the standard deviation (σ_{stat}) is defined by $\sigma_{\text{stat}}^2 = [1/(n-1)] \sum_{i=1}^n (x_i - \bar{x}_i)^2$, where σ_{stat}^2 represents the variance. This stands in comparison to POISSON NOISE and IMPULSE NOISE.

Gaussian quadrature

[computational] A NUMERICAL algorithm used to obtain the best estimate of an integral $\left(\int_a^b f(x)dx\right)$ by mathematically selecting the optimal the x -coordinates (DISTANCE from a vector point to the y -axis measured parallel to the x -axis) to be used to define the polynomial function $f(x)$ under integration. The fundamental theorem of Gaussian quadrature defines that for an n -point Gaussian quadrature, the optimal abscissas of formulas are exactly the roots of the orthogonal polynomial derived on the same interval and with the same weighting function. Gaussian quadrature accurately fits all polynomials up to the $2n - 1$ th degree. The extrapolated Lagrange interpolating polynomial used in the Gaussian quadrature through the n -points is derived as $\Phi(x) = \sum_{j=1}^n [F(x)/(x - x_j)F'(x_j)] f(x_j)$, where $F(x) = \prod_{j=1}^n (x - x_j)$.

Gaussian surface

[biomedical, electronics, general] A symmetric surface of enclosure that confines all the charges in the calculation for the electric field.

Gauss–Jordan elimination

[computational] An analytical mechanism for solving linear equations. The matrix describing the system parameters is systematically reduced as illustrated from the following three equations: $x + y + z = 3$; $2x + 3y + 7z = 0$; and $x + 3y - 2z = 17$, which is expressed in matrix format as

$$\left[\begin{array}{ccc|c} 1 & 1 & 1 & 3 \\ 2 & 3 & 7 & 0 \\ 1 & 3 & -2 & 17 \end{array} \right],$$

which eventually reduces row by row to

$$\left[\begin{array}{ccc|c} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 4 \\ 0 & 0 & 1 & -2 \end{array} \right]$$

with solutions $x = 1$, $y = 4$, and $z = -2$.

Gauss–Seidel method

[computational] A sequential iteration technique for solving n linear equations ($\vec{y} = \mathbf{A}\vec{x}$) by solving each individual equation one-at-a-time and using the prior results in the sequential solutions procedure. This process was introduced by JOHANN CARL FRIEDRICH GAUSS (1777–1855) and PHILIPP LUDWIG VON SEIDEL (1821–1896). The matrix representation has coefficients for the $n \times n$ square matrix.

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & a_{ij} & \vdots \\ a_{i1} & \cdots & a_{nn} \end{bmatrix}.$$

The parameters are sequentially defined by $x_i^{(k)} = [y_i - \sum_{j < i} (a_{ij} - x_i^{(k)}) - \sum_{j > i} (a_{ij} - x_i^{(k-1)})] / a_{ii}$, or in matrix format $\vec{x}^{(k)} = [1 / (\mathbf{D} - \mathbf{L})](\mathbf{U}\vec{x}^{(k-1)} + \vec{y})$, where $\mathbf{D}$ represents the diagonal of the matrix $\mathbf{A}$, $\mathbf{L}$ represents the parameters on the lower half of the diagonal of the matrix $\mathbf{A}$, and $\mathbf{U}$ represents the upper triangular part of the matrix $\mathbf{A}$: $\mathbf{A} = \mathbf{D} - \mathbf{L} - \mathbf{U}$. The Gauss–Seidel method relies on the fact that there

are many zero ELEMENTS in the matrix and requires that the matrix is positive symmetric or diagonally dominant. The Gauss–Seidel method is frequently used to derive the eigenvalues for a complex system.

Gay-Lussac, Joseph Louis (1778–1850)

[atomic, electronics, general] A physicist and chemist from France, contemporary of Jacques Charles. Gay-Lussac is best known for his work in FLUID DYNAMICS and GAS theory, strictly limited to ideal gasses only. It is also known as Charles' law, after JACQUES ALEXANDRE CÉSAR CHARLES (1746–1823) (see [Figure G.26](#)).



Figure G.26 Joseph Louis Gay-Lussac (1778–1850), lithograph by François-Séraphin Delpech.

Gay-Lussac's law

[atomic, electronics, general, mechanics] An equilibrium of GAS PHASE and boundary conditions expressed by JOSEPH LOUIS GAY-LUSSAC (1778–1850) in 1802 defining the relationship between PRESSURE (P) and TEMPERATURE (T) as $P/T = \text{constant}$, while the volume and quantity of the gas are kept constant. Also found as Charles' law (see [Figure G.27](#)).

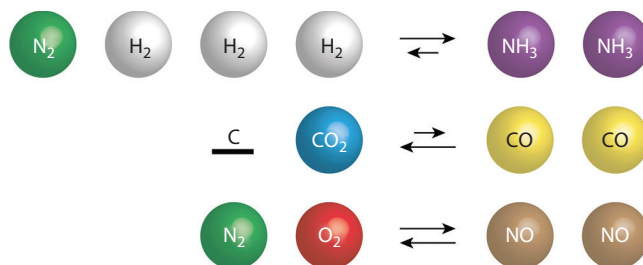


Figure G.27 The implications of the Gay-Lussac law.

Geiger, Johannes "Hans" Wilhelm (1822–1945)

[atomic, nuclear] A physicist and mathematician from Germany. Hans Geiger is world renowned for his device development for the detection of ionizing RADIATION in 1909 (GEIGER COUNTER), in particular

emitted from radio-active isotopes, which can prove harmful to human biology. In the joint effort with ERNEST MARSDEN (1889–1970) in 1909, the Geiger–Marsden experiment provided the evidence for the existence of the atomic NUCLEUS (see [Figure G.28](#)).

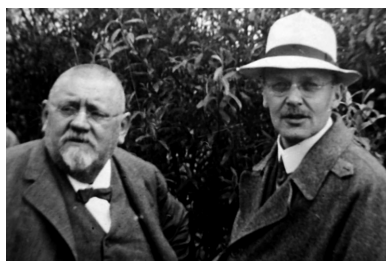


Figure G.28 Johannes “Hans” Wilhelm Geiger (1822–1945) in 1928 with Karl Scheel (left). (Courtesy of Friedrich Hund.)

Geiger and Marsden experiment

[atomic, nuclear] A PARTICLE DISPERSION experiment with gold-foil bombarded by ALPHA PARTICLES designed to define the atomic structure performed by HANS GEIGER (1822–1945) and ERNEST MARSDEN (1889–1970) in 1909 under direction of ERNEST RUTHERFORD (1871–1937). The experimental data provided conclusive evidence to support the BOHR ATOMIC MODEL, verifying the atomic NUCLEUS as a separate entity of the atomic structure.

Geiger counter

[atomic, biomedical, nuclear, thermodynamics] A device and mechanism to measure ionizing RADIATION based on scintillation designed by JOHANNES GEIGER (1822–1945) in 1909. Gas-filled GLASS bulb with low pressure gas (e.g., argon and AIR) that has a CATHODE and ANODE in the volume. The potential difference applied to the anode–cathode is slightly less than what would be required for IONIZATION. Once a charged PARTICLE enters the tube, it will ionize the GAS and a current will FLOW between the cathode and anode, counting the charge. The current duration is limited by proper configuration of an R–C network (RESISTOR–capacitor) allowing each discharge to be registered individually. Particles are not measured for IONIZATION POTENTIAL; however, the electron count provides an indication per pulse of the ENERGY of the ionizing particle. Ionizing particles measured can be alpha and beta. Geiger recognized that 1 g of radium ISOTOPE generates 3.57×10^{10} ALPHA PARTICLES per SECOND. Using the measured current generated by each discharge can provide the charge of the ionizing particle. Geiger worked closely WITH ERNEST RUTHERFORD (1871–1937) on this as a post-doctorate researcher. In literature, one may find this listed as a Geiger–Müller counter, based on the input of ERWIN WILHELM MÜLLER (1911–1977) on later refinements.

Geiger–Müller counter (Geiger–Mueller counter)

[atomic, biomedical, nuclear, thermodynamics] A device designed by Hans Geiger in 1908 and refined and produced in collaboration with WALTHER MÜLLER (1905–1979) in 1928 (see **GEIGER COUNTER**).

Geiger–Müller (G–M) tube

[atomic, nuclear] A sealed gas-filled GLASS tube with a special CATHODE–ANODE configuration used in the GEIGER COUNTER.

Geiger–Nuttall law

[atomic, nuclear, thermodynamics] The alpha-decay process can be described energetically as if the ALPHA PARTICLE is TUNNELING through a POTENTIAL BARRIER of Coulomb forces, both attractive and repulsive $\log(\tau_{1/2}) \cong aZ/\sqrt{Q_d} + b$, with for heavy nuclei $a = 1.454$ and $b = -46.83$ constants, and the DECAY time depends on the atomic number (Z). The decay ENERGY was derived by JOHN MITCHELL NUTTALL (1890–1958) in collaboration with JOHANNES WILHELM GEIGER (1822–1945) in 1911.

Geiger–Nuttall rule

[atomic, nuclear] See **GEIGER–NUTTALL LAW**.

Geitel, Hans Friedrich Karl (1855–1923)

[nuclear] A physicist and high-school teacher from Germany. Geitel worked on the electron discharge from nonelectrode metals under irradiation by ionizing RADIATION and ULTRAVIOLET light, experimentally verifying the photo-electric effect. Other work by Geitel was related to “atmospheric ELECTRICITY,” for example, LIGHTNING and cosmic radiation. The work by Geitel provided elementary revelations about the nature of radioactive isotopes (see [Figure G.29](#)).



Figure G.29 Hans Friedrich Karl Geitel (1855–1923) Geitel, with Johann Philipp Ludwig Julius Elster (1854–1920).

Gell-Mann, Murray (1929–)

[energy, general, quantum, relativistic] A physicist from the United States. Murray Gell-Mann along with GEORGE ZWEIG (1937–) provided evidence that BARYONS (as well as the other HADRON group: mesons) are not primary ELEMENTARY PARTICLES (see [Figure G.30](#)).



Figure G.30 Murray Gell-Mann (1929–) in 2012. (Courtesy of World Economic Forum, Geneva, Switzerland.)

General nuclear reaction

[nuclear] An equation describing the DECAY of an ISOTOPE under the CONSERVATION LAWS; for example, the decay of uranium-238, producing thorium, is written as ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{234}\text{Th} + {}_2^4\text{He} + \gamma$, respectively, concerning a collision ${}_2^4\text{He} + {}_7^{14}\text{N} \rightarrow {}_8^{17}\text{O} + {}_1^1\text{H}$.

General theory of relativity

[computational, general] A theoretical description of the space-time CONTINUUM by ALBERT EINSTEIN (1879–1955) in 1915, linking the PERCEPTION of time to the perception of space. The concept of GRAVITATION is the major component of this theoretical description (1915). In astronomy, Einstein used this theory to predict that stellar binary ORBITS will progressively DECAY through emission of a concept captured by “gravitational radiation.” The general theory links gravitation to time distortion, both induced by “neighboring” massive object as well as the rotation of the EARTH with respect to time measured at altitude (moreover moving into outer space). This relates to Einstein’s SPECIAL THEORY OF RELATIVITY published in 1905.

Generalized adiabatic availability

[thermodynamics] The transfer of ENERGY when considering two energy states of a complex system with r constituents and ENTROPY (S) that are closely ranked together (“neighbors”) has an ADIABATIC AVAILABILITY as the energy difference between the neighboring unstable and stable EQUILIBRIUM STATE $\Psi_{\text{adiab}} = E - E_s(S, n, \vec{\beta})$, where $\vec{\beta} = (\beta_1, \beta_2, \beta_3, \dots, \beta_{i_1}, \dots, \beta_r)$ are the system parameters (e.g., forces, boundary conditions, volume), and E_s is the energy of a stable equilibrium, whereas E is the state that is not necessarily stable and may not have the same number and quantities (n) of constituents. The stable equilibrium will have a stable temperature (T_s) that allows the adiabatic availability to be written in differential form as $d\Psi_{\text{adiab}} = dE - T_s(S, n, \beta)dS$. The “weight” of a system limits the variables to a single independent property only.

Generator

[general] A device that has a mechanical mechanism in place to convert one form of ENERGY into electrical energy. Examples are hydroelectric plant, wind generator, or nuclear power plant. The principle energy conversion comes to a rotating coil interacting with a MAGNETIC FIELD. The magnetic field can be a PERMANENT magnet, a coil or a stator. The magnetic field direction may move or may be fixed in both time and place. A generator can produce either a VOLTAGE (V) and current fluctuating over time with sinusoidal pattern directly related to the ANGULAR VELOCITY (ω) of the rotation of the mechanism $V = V_0 \sin((\omega/2\pi)t + \phi)$, where ϕ is a phase ANGLE that is device dependent, alternatively may in limited cases be steady state. Linking more than one generator together will illustrate the importance of the phase angle for each device, even when operating at nearly identical revolutions. A cluster of synchronous generators will induce significant risk for electric and mechanical losses and temperature rise with resulting reduced energy generation efficacy (see Figure G.31).

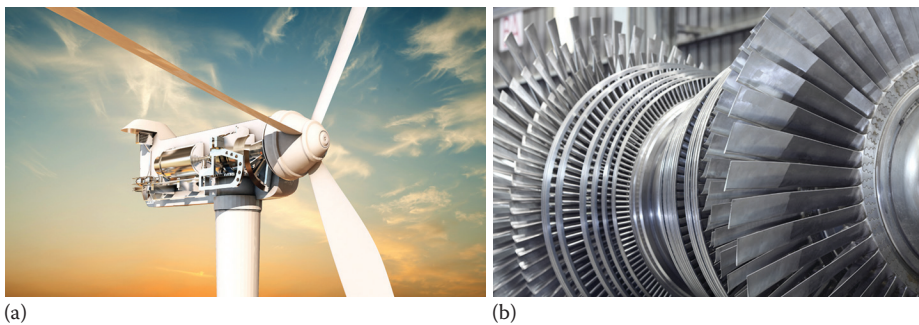


Figure G.31 (a) Wind generator and (b) rotor for a coal burning steam turbine electric generator.

Genetic algorithm

[computational] An empirical search that emulates a naturally evolving process, incorporating a “learning” mechanism. The heuristic computational mechanism of “natural selection” resembles the biological process, specifically in genetics (Darwin’s principle: survival of the fittest). The process originated at the onset of cybernetics in the 1940s.

Genomics

[biomedical, computational, theoretical] A comprehensive breakdown of the inherited information-bearing genetic material residing in the chromosomes (and hence DNA) of an organism’s (i.e., genome). DNA is a biopolymer consisting of four nucleotide constituents: A (adenine), C (cytosine), G (guanine), and T (thymine). The study includes the analysis of the full complement of signaling codes that regulate the gene expression. Genomics focuses on species, not on individuals. The name originates from a journal title introduced in 1986 that publishes work related to gene sequencing, mapping and their activities. The information in the chromosomes is digital, consisting of DNA strings whose order provides information in 0s and 1s. Genomics is hence an information science. The study requires the establishment of a “reference genome” for a species of interest to provide a basis for the analysis of the global genomic composition and associated expressions. The most comprehensive DNA sequence-based investigation is the Human Genome Project.

Geocentric

[general, geophysics] A physical model of the UNIVERSE with the EARTH as the center, if not as the center of the SOLAR SYSTEM. This belief was documented by the Greek philosopher PTOLEMY (c. 90–168 AD) around 140 AD and was generally held as the standard until the seventeenth century. This stands opposing the

HELIOCENTRIC model, placing the SUN in the center of our celestial system, the current and verified model (see [Figure G.32](#)).

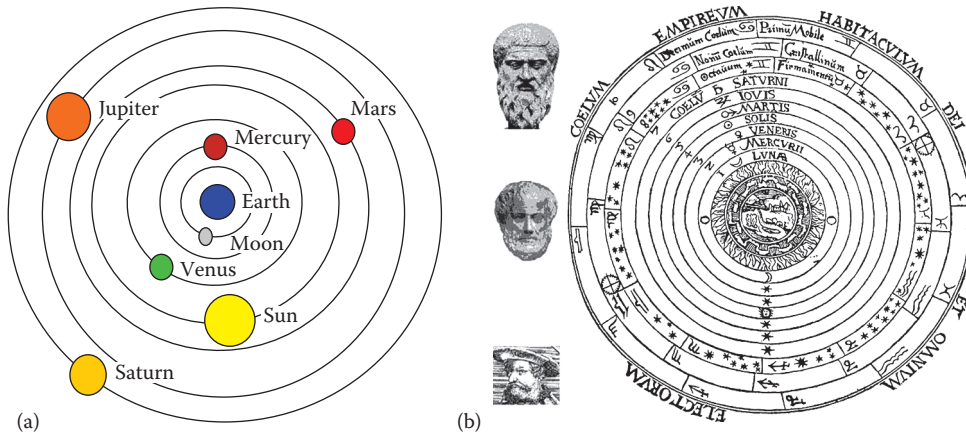


Figure G.32 (a) The model of the “universe” as described by Ptolemy (c. 90–168 AD). (b) Dante’s (Durante degli Alighieri [Dante Alighieri] [1265–1321], poet from Italy) interpretation of the celestial configuration, portrayed by Ratel; Magasin Pittoresque, Paris, France, in 1850.

Geodesy

[general, geophysics] The study of the shape of the EARTH, divided into two aspects: ellipsoidal shape (in three-dimensional view: spheroid) derived from sea level and the determination of the deviation for the physical sea level (i.e., “geoid”) from the perfect spheroid. The Earth deviates from a spheroid in an additional manner that the POLES are “lower” (see [Figure G.33](#)).



Figure G.33 Geoid shape of the Earth in exaggerated form.

Geographic north

[geophysics, mechanics] A reference point indicating the axis of rotation when referenced against the GEOGRAPHIC SOUTH pole. Note that the axis of rotation is not the same axis that connects the MAGNETIC NORTH POLE to the MAGNETIC SOUTH POLE. Hence, the magnetic north pole is not in the same location as the geographic north pole (see [Figure G.34](#)).

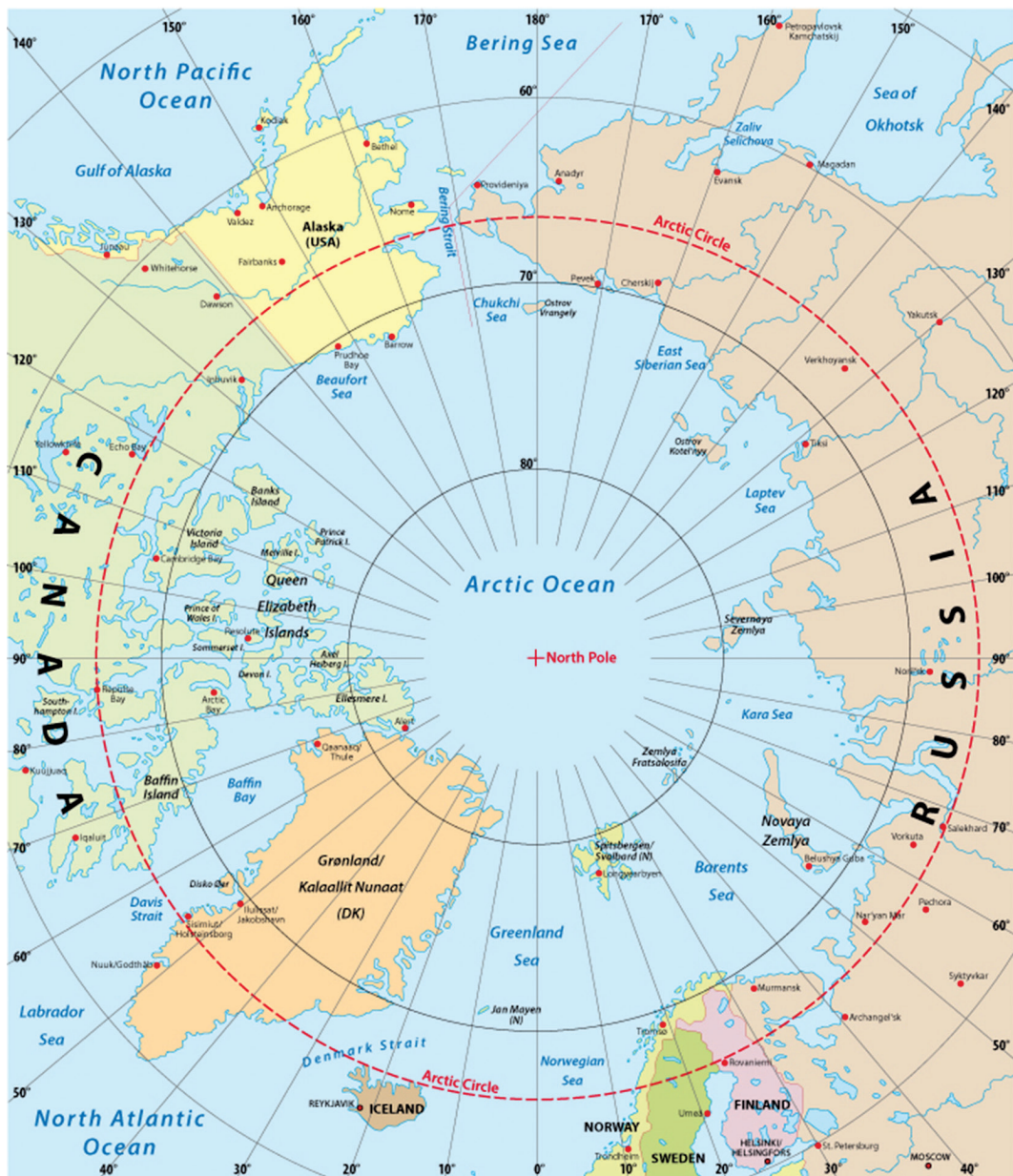


Figure G.34 Geographic location of the north point, the magnetic North and South Pole, respectively, are continuously shifting (drifting) as shown under magnetic pole. The axis of rotation is not indicated on this map, but does not coincide with the location of the North Pole center.

Geographic south

[geophysics, mechanics] A reference point indicating the axis of rotation when referenced against the GEOGRAPHIC NORTH pole. Note that the axis of rotation is not the same axis that connects the MAGNETIC NORTH POLE to the MAGNETIC SOUTH POLE. Hence, the magnetic south pole is not in the same location as the geographic south pole (see [Figure G.35](#)).



Figure G.35 Geographic location of the south point intersect of the longitudinal lines.

Geography

[astronomy/astrophysics, geophysics] The study of the relief and location of features, phenomena, and inhabitants on the surface of the **PLANET EARTH**. From Greek γεωγραφία meaning “Earth description.” It is also referred to as cartography, the development of charts and maps, illustrating the local statistical values for specific parameters.

Geomagnetic poles

[general] On every magnetic device, there will be two **POLES** that have **MAGNETIC FIELD** lines starting and finishing, with the field lines at perpendicular orientation to the local surface. For **EARTH** (from the Greek γῆ [ge]), the **MAGNETIC POLES** are at the short axis of the ellipsoid, the **NORTH** and south poles, respectively. The magnetic poles are continuously changing location and have flipped north–south at least a documented 65 times over the past 600 million years (see **MAGNETIC AXIS**) (see [Figure G.36](#)).

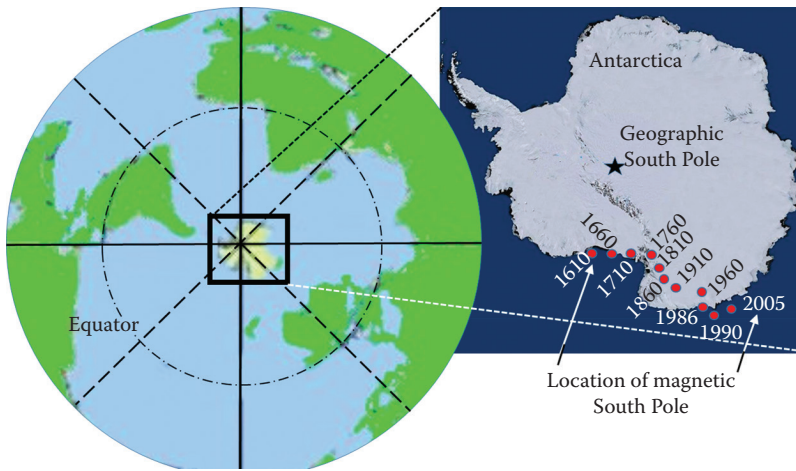


Figure G.36 Drift of the location of the magnetic South Pole over the past 400 years.

Geomagnetism

[electromagnetism, quantum] The inherent magnetic features of the **PLANET EARTH**. The local earth’s **MAGNETIC FIELD** strength and direction (vector) can be mapped and appears to shift with time. Based on geological findings, it can be shown that the earth’s magnetic field switches **POLES** (**NORTH**–**south**) on average every 11 million years.

Geometric center as the center-of-mass

[general] The center of an object found in the intersect of lines drawn from opposite extremes in three or more directions (see [Figure G.37](#)).

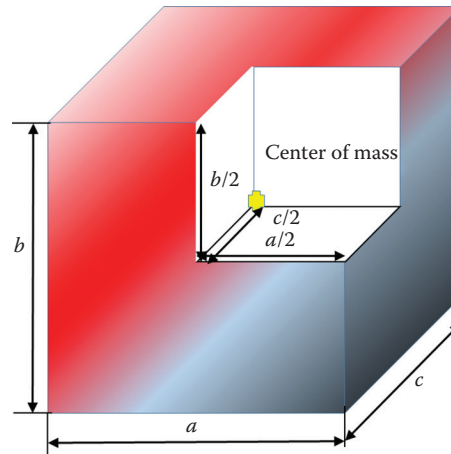


Figure G.37 Geometric center of mass.

Geometrical moment of inertia

[fluid dynamics, general, mechanics] A moment of INERTIA calculated in a simplified manner, using the parallel axis as the reference and calculating the moment of inertia ($I_{||}$) based on global variables such as the sum of the moment of inertia about the axis through the center of mass (I_{cm}) and the total mass (m_{tot}) times the maximum radius of a circular CROSS SECTION (R): $I_{||} = I_{cm} + m_{tot}R^2$ (see **MOMENT OF INERTIA**).

Geometrical optics

[general, optics] A geometric description of the tracks of rays of particles, consistent with the WAVE-PARTICLE DUALITY of light. There are five laws that describe geometrical optics: the law of rectilinear propagation, LAW OF REFLECTION, LAW OF REFRACTION, law of diffraction, and the LAW OF CONSERVATION OF ENERGY. Ray tracing is a specific example of geometric optics (see [Figure G.38](#)).

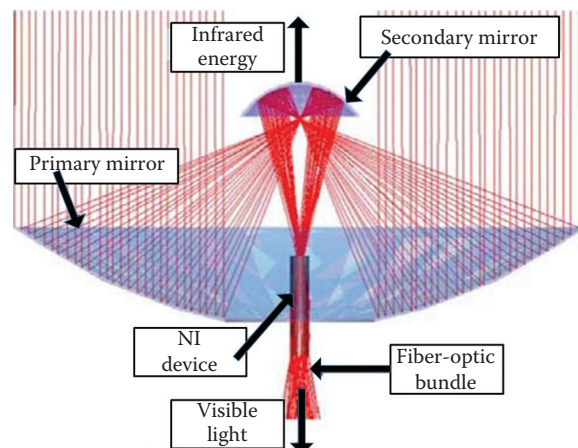


Figure G.38 Ray trace for a lens design.

Geophysics

[acoustics, astronomy/astrophysics, chemical, electromagnetism, fluid dynamics, geophysics, mechanics, solid-state, thermodynamics] The study of the physical phenomena of a PLANET as well as the ATMOSPHERE and LIQUID bodies (i.e., oceans). Geophysics can be subdivided into various subcategories depending on the school of thought, primarily ATMOSPHERIC PHYSICS, CLIMATOLOGY, GEODESY, GEOMAGNETISM and ELECTRICITY, HYDROLOGY, METEOROLOGY, OCEANOGRAPHY, RHEOLOGY, SEISMOLOGY (TECTONICS), and under certain conditions geology. Generally, geophysics entails the mathematical description of the processes and properties observed in the static field of geology (see [Figure G.39](#)).



Figure G.39 Geophysics of a geyser.

Geostationary orbit

[astrophysics, general, mechanics] A SATELLITE orbit that completes one revolution around the EARTH in the same time as the Earth completes one full revolution. The placement of the satellite is such that the ORBITAL VELOCITY and DISTANCE to the earth's center of mass creates a CENTRIPETAL FORCE with normal component that cancels out the gravitational attraction. The distance (d) from the center of mass of Earth with mass (M_E) to the satellite is $d = (GM_E/(T/2\pi)^2)^{1/3}$, where G is the gravitational constant and T is the period of the revolution (see [Figure G.40](#)).



Figure G.40 Geostationary communication satellites.

Geosynchronous orbit

[astrophysics, general] See GEOSTATIONARY ORBIT.

Gerlach, Walther (1889–1979)

[atomic, nuclear, quantum] A physicist from Germany. In collaboration with OTTO STERN (1888–1969), Gerlach discovered the atomic ELECTRON SPIN quantization in a MAGNETIC FIELD in 1920, the Stern–Gerlach effect. This observation was made 2 years prior to the official definition of SPIN (see [Figure G.41](#)).



Figure G.41 Walther Gerlach (1889–1979).

Germer, Lester Halbert (1896–1971)

[atomic, computational, nuclear] A physicist from the United States. Germer investigated the de Broglie notion that any and every moving object has a WAVE function associated with it. In collaboration with CLINTON JOSEPH DAVISSON (1881–1958), this phenomenon was experimentally verified in 1927, DAVISSON–GERMER EXPERIMENT (see [Figure G.42](#)).



Figure G.42 Lester Halbert Germer (1896–1971) on right with Clinton Joseph Davisson (1881–1958); picture taken with a vacuum tube that was used in the electron diffraction experiments performed under the Davisson–Germer experiment, while they were working at Bell Laboratories. Davisson received the Nobel Prize for his efforts in 1937, taken in 1927.

Gerstner, František Josef (1789–1823)

[fluid dynamics] A scientist from Czechoslovakia, now Czech Republic. Gerstner's interests were in fluid-dynamical MOTION, specifically at the surface and related to the rotational nature of SURFACE WAVES, building on the concepts introduced by SIR ISAAC NEWTON (1642–1727) in his 1687 *Principia* (see [Figure G.43](#)).



Figure G.43 František Josef Gerstner (1789–1823).

Gerstner's waves

[fluid dynamics] Rotational waves in an infinitely deep LIQUID described by FRANTIŠEK JOSEF GERSTNER (1789–1823) in 1802. Gerstner made the following three assumptions: points at the crest of WAVE travel up and forward; ELEMENTS moving at the trough of the wave travel in downward and backward direction; the combined effects of PARTICLE motions outline a circle. Gerstner defined the location of the MOTION of a particle in a surface wave with horizontal location (x) and vertical direction (y) as $x = a + (1/k)e^{ky} \sin(k\{a + vt\})$, where $k = 2\pi/\lambda$ is the wave number for wavelength λ , v is the propagation velocity of the wave, a and b are parameters used to identify a specific particle in the wave. The rotational motion was verified by both ERNST WEBER (1795–1878) and WILHELM WEBER (1804–1891); the latter built a wave tank for experimental verification (first of its kind) (see [Figure G.44](#)).

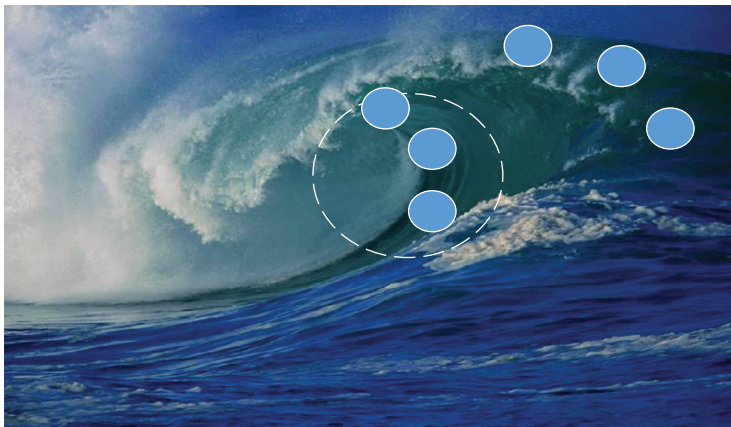


Figure G.44 Gerstner wave.

g-factor, electron orbital (g_L)

[atomic, energy, nuclear, optics] A correction factor on the total magnetic moment (μ_L) resulting from the orbital angular momentum ($\vec{L}$), expressed as $\vec{\mu}_L = -g_L(\mu_B/\hbar)\vec{L}$, where $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, and $\mu_B = e\hbar/2m_e$ the BOHR MAGNETON. For the components that align with the precision axis, this reduces to $\mu_L = g_L\mu_B m_\ell$, where m_ℓ is the MAGNETIC QUANTUM number and $g_L = 1$.

g-factor, electron spin (g_e)

[atomic, energy, nuclear, optics] The MUON has a SPIN similar to the electron with magnetic moment $\vec{\mu}_m = g_e(\mu_B/\hbar)\vec{S}$, where $\vec{S}$ is the spin angular momentum of the electron, $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, $\mu_B = e\hbar/2m_e$ the BOHR MAGNETON, m_e the electron mass, and $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron charge. Note also used $g_s = |g_e|$. The value for g_s can be derived from the DIRAC EQUATION.

g-factor, muon (g_μ)

[atomic, energy, nuclear, optics] The MUON has a SPIN similar to the electron with magnetic moment $\vec{\mu}_m = g_\mu(e/2m_\mu)\vec{S}$, where $\vec{S}$ is the spin angular momentum of the muon, e the electron charge, and m_μ the muon mass.

g-factor, nuclear (g_n)

[atomic, energy, nuclear, optics] The magnetic moment as a result of the nuclear SPIN with respect to protons, NEUTRON is linked to the nuclear spin angular momentum (I_{spin}) as $\mu_n = g_n(\mu_N/\hbar)I_{\text{spin}}$, where $\mu_N = e\hbar/2m_p$ the nuclear MAGNETON, and $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, m_p the PROTON mass, and $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron charge. It is also referred to as NUCLEON g-factor.

g-factor, total angular momentum (g_J)

[atomic, energy, nuclear, optics] A correction factor for the total magnetic moment resulting from the TOTAL ANGULAR MOMENTUM ($\vec{J} = \vec{L} + \vec{S}$, $\vec{L}$ the orbital angular momentum of the electron and $\vec{S}$ the SPIN angular momentum) $\vec{\mu}_J = -g_J(\mu_B/\hbar)\vec{J}$, where $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, $\mu_B = e\hbar/2m_e$ the BOHR MAGNETON. It is also referred to as the Landé factor. (Note: the total angular momentum g-factor is correlated with the electron-orbital g-factor (g_L) and the ELECTRON SPIN g-factor ($g_s = |g_e|$, the absolute value of the electron g-value) by QUANTUM mechanical principles defined through $\vec{\mu}_J = \vec{\mu}_L + \vec{\mu}_S = \vec{L}g_L\mu_B + \vec{S}g_s\mu_B$, yielding $g_J = g_L \frac{[\vec{J}(\vec{J}+1) - \vec{S}(\vec{S}+1) + \vec{L}(\vec{L}+1)]}{[2\vec{J}(\vec{J}+1)]} + g_s \frac{[\vec{J}(\vec{J}+1) + \vec{S}(\vec{S}+1) - \vec{L}(\vec{L}+1)]}{[2\vec{J}(\vec{J}+1)]}$, where $\vec{J}$ is the total electronic angular momentum ($|\vec{J}| = j(j+1)\hbar$, j the angular QUANTUM NUMBER, expressed as operator $\vec{J}^2\Psi = \hbar j(j+1)\Psi$), $\vec{L}$ the orbital angular momentum (also referred to as rotational angular momentum) derived from the WAVE function Ψ as an operator ($\vec{L}^2$): $\vec{L}^2\Psi = \hbar\ell(\ell+1)\Psi$, g_L the electron-orbital g-factor, where the wave function is a complex function analog to a harmonic OSCILLATOR although in QUANTUM MECHANICS describing the PROBABILITY function of the position.) The value $|\Psi|^2$ is real and provides a probability distribution for the location of the PARTICLE in MOTION at a given time when the location is derived from observation, g_s the electron-spin g-factor, and $\vec{S} = \epsilon_0 \int (\vec{E} \times \vec{A}) d^3r$ the spin angular momentum, with ϵ_0 the permittivity of VACUUM, $\vec{E}$ the electrical field, and $\vec{A}$ the area or vector potential.

Gibbon, John Heysham, Jr. (1903–1973)

[biomedical] A cardiovascular surgeon from the United States who invented the first working lung–HEART machine in 1937. The work of Gibbon was based on the pioneering efforts of ex vivo oxygen exchange performed by another vascular surgeon ALEXIS CARREL (1873–1944) (see [Figure G.45](#)).

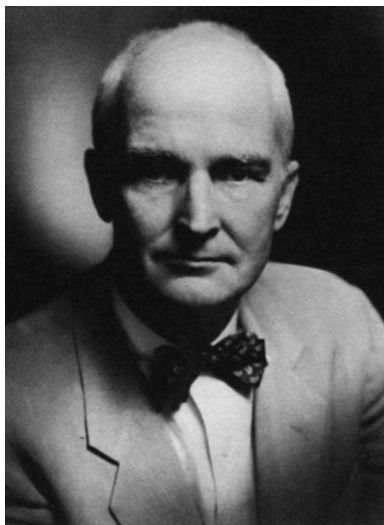


Figure G.45 John Heysham Gibbon, Jr. (1903–1973): photograph by Fabian Bachrach. (Courtesy of National Academy of Sciences, Washington, DC.)

Gibbs, Josiah Willard (1839–1903)

[biomedical, general, mechanics, thermodynamics] A physicist from the United States. Josiah Gibbs introduced and verified the Gibbs free ENERGY concept. Additional work of Gibbs was in vector analysis and ELECTROMAGNETIC THEORY (see [Figure G.46](#)).

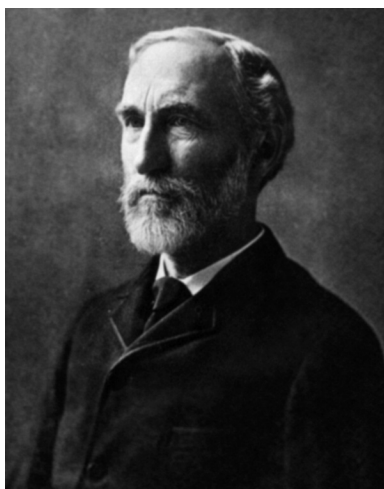


Figure G.46 Josiah Willard Gibbs (1839–1903).

Gibbs free energy (G)

[biomedical, general, solid-state, thermodynamics] ENERGY that determines whether a reaction will be spontaneous or forced, introduced by JOSIAH WILLARD GIBBS (1839–1903). The Gibbs free energy is defined as the change in enthalpy minus the temperature times the entropy

$G = E_{\text{Helmholtz}} + PV = U + PV - TS$, where $E_{\text{Helmholtz}}$ is the Helmholtz free energy, P is the pressure, V is the volume, T is the temperature, and S is the entropy of the system. The Gibbs free energy for forced or unfavorable (not spontaneous) reactions is positive ($G > 0$) and are identified as endergonic. Reactions will be spontaneous if the free energy is negative ($G < 0$) and are classified as EXERGONIC. During redox reactions, the Gibbs free energy is equal to the maximum electric work $\Delta G^0 = -nF_{\text{Helmholtz}}\Delta V^0$, where the superscript “o” indicates standard conditions (25°C temperature and 1 atm pressure) and ΔV^0 is the electric potential. It can be shown that at any temperature, the energy balance is represented as $\Delta G = \Delta G^0 + RT \ln Q_r$, where $R = 8.314 \text{ J/molK}$ is the GAS constant and Q_r is the reaction quotient. In biological cells, this can be used to illustrate the transmembrane electrical POTENTIAL (V or ε_{emf}) that occurs as a result of the difference in ionic concentrations [C_{ion}] in the intracellular versus the extracellular space. The result is expressed as the NERNST EQUATION, also referred to as the NERNST POTENTIAL $\Delta \varepsilon_{\text{emf}} = \Delta \varepsilon_{\text{emf}}^0 - (RT/nF_{\text{Helmholtz}}) \ln Q_r$, with ε_{emf} the electromotive transmembrane potential. This equation also provides the potential difference generated in a galvanic CELL as a function of the ION concentrations in both compartments. The Nernst potential is defining the RESTING POTENTIAL during equilibrium. In this equation, Q_r states the ratio of the extracellular to intracellular ion concentrations. The Nernst equation only represents the most simple case in which the CELL MEMBRANE is permeable to one type of ions (for instance, only POTASSIUM (K^+) ions) (see Figure G.47).

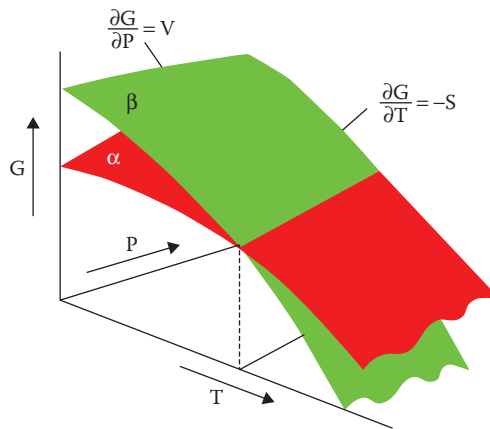


Figure G.47 Graphical representation of the Gibbs free energy concept.

Gibbs free energy of van der Waals gas

[thermodynamics] The van der Waals GAS has the characteristics of a liquid–GAS

PHASE TRANSITION at constant pressure. The Gibbs free ENERGY is adjusted as follows:

$G(T, V, N) = [NTV/(V - Nb_w)] - (2N^2a_w/V) - NT \left\{ \log \left(n_Q [(V - Nb_w)/N] \right) + 1 \right\}$, where T is the temperature, N is the number of atoms, V is the volume, the definition of the QUANTUM CONCENTRATION (Note: the “van der Waals gas” is a QUANTUM GAS) $n_Q = (mT/2\pi\hbar^2)^{3/2}$ with $\hbar$ the Planck constant (h) divided by 2π and m the mass of the gas, a_w and b_w constants tying the pressure ($P_c = a_w/27b_w^2$), temperature ($T_c = 3a_w/27b_w$), and volume ($V_c = 3Nb_w$) to a reference point, primarily the critical point, as derived from the PV-curve (also see LAW OF CORRESPONDING STATES). The $\hat{P}\hat{V}$ -curve (Note: $\hat{X} = X/X_c$) allows for the

determination of a_w and b_w at the point (critical point) that satisfies the following two conditions (minimum or maximum): $(\partial \hat{P} / \partial \hat{V})_{\hat{T}} = 0$ and $(\partial^2 \hat{P} / \partial \hat{V}^2)_{\hat{T}} = 0$.

Gibbs paradox

[thermodynamics] QUANTUM thermodynamics concept introduced by JOSIAH WILLARD GIBBS (1839–1903) describing the discontinuity in entropy for a two-component system, each with its own entropy, energy, and number of molecules that changes under external influences. When both constituents suddenly become alike (for reasons not to be discussed), the difference in entropy between the two constituents instantaneously reduces to zero.

Gibbs relation

[thermodynamics] The differential internal ENERGY (dU) between two states that are neighbors and at equilibrium but differ in entropy by amount dS , expressed as $dU = TdS - PdV + \mu_1 dn_1 + \mu_2 dn_2 + \mu_3 dn_3 + \cdots + \mu_r dn_r$, where P is the pressure, V is the volume, T is the temperature, S is the entropy of the system, μ_i is the chemical potential of the respective constituents, and n_i is the respective quantities of constituents.

Gibbs–Dalton mixture

[thermodynamics] Description of ideal gases that are composed of multiple constituents (r) of respective quantity n_i , each with a pressure P_{ii} assembled in a volume V at temperature T . The mixture has negligible interaction between the respective constituents. In case all except one of the components are removed there will be no change in the volume occupied by that constituent. This can be defined theoretically as a collective that satisfies the following three conditions: volume $n_i V_{ii}(T, P_{ii}) = V$ for each respective component, where V_{ii} is the volume of one ELEMENT of the component; internal ENERGY $U(T, P, \vec{n}) = \sum_{i=1}^r n_i U_{ii}(T, P_{ii})$; and entropy $S(T, P, \vec{n}) = \sum_{i=1}^r n_i S_{ii}(T, P_{ii})$.

Gibbs–Duhem relation

[thermodynamics] When combining the GIBBS RELATION and the EULER RELATION for enthalpy ($H = U + PV$) to give $H = TS + \mu_1 n_1 + \mu_2 n_2 + \cdots + \mu_r n_r$, and the HELMHOLTZ FREE ENERGY ($E_{\text{Helmholtz}} = U - TS$) as $E_{\text{Helmholtz}} = -PV + \mu_1 n_1 + \mu_2 n_2 + \cdots + \mu_r n_r$ and the Gibbs free ENERGY as defined under the Euler relation: $G = \mu_1 n_1 + \mu_2 n_2 + \cdots + \mu_r n_r$ to yield another condition for the change in temperature and pressure under constant entropy as: $SdT - VdP + \mu_1 n_1 + \mu_2 n_2 + \cdots + \mu_r n_r = 0$. Introduced by the French physicist and mathematician PIERRE DUHEM (1861–1916).

Gilbert, William (1540–1603)

[general] Physician, astronomer, and physicist from Great Britain who proposed a new concept of the earth's MAGNETIC FIELD. He stated that the earth's magnetic field originates at the POLES of a spherical LODESTONE-shaped EARTH in 1600. This was an advancement over the spheroid model introduced by NICOLAUS COPERNICUS (1473–1543). Initially, it was thought that a compass needle pointed to the "heavens." Gilbert outlined the path of the magnetic field lines of a BAR MAGNET with a compass to illustrate the concept. Descartes followed through on this with IRON filing on a sheet of paper placed on top of a bar MAGNET in around 1645. William Gilbert also described the influence of the MOON on the tides. He was

also an advocate of a sun-centered SOLAR SYSTEM. Gilbert also erroneously assumed that MAGNETISM was the source for driving the planetary attraction, not GRAVITATION (see [Figure G.48](#)).



Figure G.48 William Gilbert (1540–1603).

Gillet, Joseph Anthony (1837–1908)

[general] Scientist from the United States who proposed the existence of an AETHER for the transmission of ELECTROMAGNETIC RADIATION in 1882. Other work by Gillet together with WILLIAM JAMES ROLFE (1827–1910) describes the chemical interaction and the interchanges in forces between chemistry and ELECTRICITY (see [Figure G.49](#)).

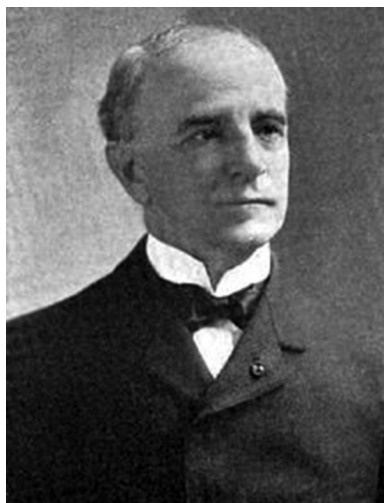


Figure G.49 Joseph Anthony Gillet (1837–1908).

Glancing collision

[general] PARTICLE collision where the paths do not align. In this situation, the momentum is split in linear and orthogonal components in order to satisfy the CONSERVATION LAWS (see [Figure G.50](#)).

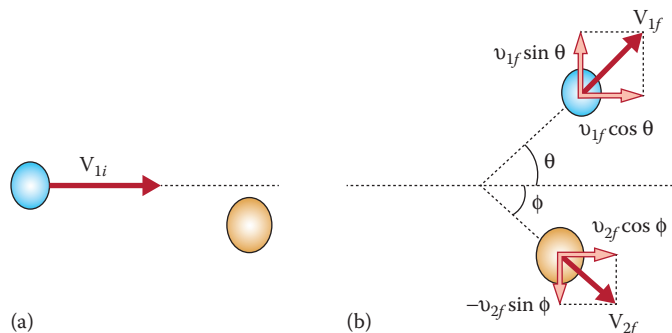


Figure G.50 Glancing collision: (a) before the collision and (b) after the collision.

Glashow, Sheldon Lee (1932–)

[atomic, general] Scientist from the United States who introduced the formal assumption of an idea that was discussed regarding the existence of a total of four quarks, similar to the known existence of four leptons. Nobel Prize winner for his work on the ELECTROWEAK force theory (see [Figure G.51](#)).



Figure G.51 Sheldon Lee Glashow (1932–) on the right during the Origins Symposium at Arizona State University in Tempe, Arizona, in 2009.

Glass

[solid-state] Amorphous material that has no distinguishable order or periodicity (not a crystal) that is transparent to most visible and INFRARED light and some ULTRAVIOLET as well as long wavelength ELECTROMAGNETIC RADIATION (e.g., RADIO, television). Most glass substances (depending on the chemical structure) are not a solid but display several LIQUID phase characteristics. Window panes use glass. Old window panes will show sagging over long periods of time, where the structure becomes less defined, making the IMAGE

formation through the glass subject to deformities and the bottom side will increasingly become thicker, while the top decreases in thickness. Materials used for the fabrication of the general garden variety glasses are silicon oxide [“vitreous silica”] (SiO_2), arsenic trisulfide (As_2S_3), and the incorporation of other oxides such as Na_2O or B_2O_3 with different transmission spectra. Generally, the use of the word glass for a transparent medium is classified based on the production process (see [Figure G.52](#)).



Figure G.52 Examples of the use and appearance of glass products: (a) house with glass windowpanes and (b) heating glass in furnace for glassblower applications.

Global positioning system (GPS)

[general, geophysics] Coordination system relying on the earth's MAGNETIC FIELD lines to determine the longitude and LATITUDE of the recording device, and as such define the location of the user. The GPS relies on the fixed (geostationary) position of a number of satellites (24 total), each in a 12 h orbit. The satellites are referenced with respect to each other and with respect to the earth's magnetic field. The beacon signals emitted by the respective satellites are captured by receiver stations (e.g., mobile phones) that will define the location of the receiver station with respect to the global geometry. The satellites continuously send out their position information and this is used to cross-correlate with respect to the remaining satellites in orbit for global referencing. A minimum of four satellites are used to define the position of a device. Additional linking with existing maps a path which can be outlined from point “A” to point “B,” all with respect to the observer's location. The GPS navigation system will need to include the SPECIAL THEORY OF RELATIVITY to maintain accuracy. Without special relativistic calculations the determination of the location would be accurate only within several kilometers, whereas state of the art is accurate within meters. Land-based reference signals can enhance the positioning accuracy further (see [Figure G.53](#)).



Figure G.53 Representation of the satellite configuration for the global positioning system.

Global symmetry

[computational, general] A system that is invariant under transforms, such as rotation of the reference frame or linear translation (i.e., GLOBAL TRANSFORMATION). The length and respective ANGLES to the edges remain constant. A car driving on the highway will not change configuration, while retaining its own reference frame, or within the reference frame of a passing car.

Global transformation

[computational, general] Linear transformations of a system with associated parameters (e.g., mass, length) and described by functions (e.g., OSCILLATION), such as rotation or translation.

Globe, oscillations of a liquid

[fluid dynamics] Finite oscillations of a LIQUID in an ellipsoidal configuration. The ellipsoid has three principal axes: a , b , and c in a Cartesian coordinate system (x, y, z) . The axes will have a rate of change associated with the OSCILLATION that is described as: $\dot{a} = \partial x / \partial t$, $\dot{b}$, and $\dot{c}$. The VELOCITY POTENTIAL (Φ_v) profile will satisfy $\Phi_v = -(1/2)((\dot{a}/a)x^2 + (\dot{b}/b)y^2 + (\dot{c}/c)z^2)$, with boundary conditions: $(\dot{a}/a) + (\dot{b}/b) + (\dot{c}/c) = 0$, since this is for traveling RESONANCE, not EXPANSION.

Globe valves

[fluid dynamics] Tortuous FLOW and gating mechanism with high flow RESISTANCE as one of several VALVE configuration (see Figure G.54).

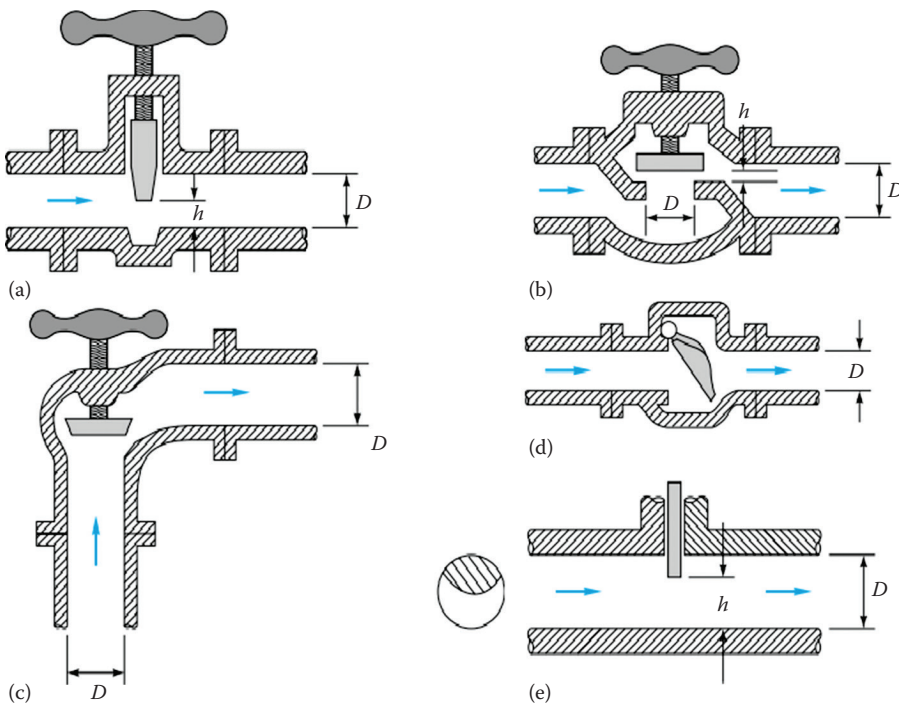


Figure G.54 Valve configurations: (a) gate valve, (b) globe valve, (c) angle valve, (d) swing-check valve, and (e) disk-type gate valve.

Glow discharge

[atomic, nuclear] Corona electron discharge between two charged (opposite) “electrodes” when the pressure (and hence the potential for IONIZATION of the GAS at low density) drops below a critical pressure. This luminous discharge is diffuse. This is in contrast to SAINT ELMO’S FIRE (see [Figure G.55](#)).



Figure G.55 Glow discharge on roof top. (Courtesy of Joe Thomissen.)

Glucose

[biomedical, chemical] CARBOHYDRATE chemical as one of the primary sources of cellular nutrition: $C_6H_{12}O_6$. Glucose oxides as follows: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$. The breakdown of glucose is referenced as the KREBS CYCLE. The Krebs cycle generates a total of 30 molecules of ATP per molecule of glucose. The conversion efficiency is very high, perhaps the highest for biologically viable ENERGY production. A specific variety of glucose is used in positron emission TOMOGRAPHY, FLUORODEOXYGLUCOSE.

Gluon

[general, high-energy, nuclear] STRONG NUCLEAR FORCE between quarks is represented by the exchange of a BOSON messenger designated as a gluon to form hadrons. The force represented by the gluon is called COLOR force. In QUANTUM mechanical theory, the gluon is a massless PARTICLE also called a VECTOR BOSON with “four-dimensional” Schrödinger WAVE functions with SPIN 1 and is magnetically neutral. Emission of a gluon can change the “color” of a QUARK, however it cannot change the “FLAVOR” OF THE QUARK. There are eight different gluons associated with the eight different potential quark couplings. The gluon color phenomenon is described by QUANTUM CHROMODYNAMICS.

Glycogen

[biomedical, chemical] Biopolymer form of GLUCOSE that supports storage in a polysaccharide form (i.e., starch) (see [Figure G.56](#)).

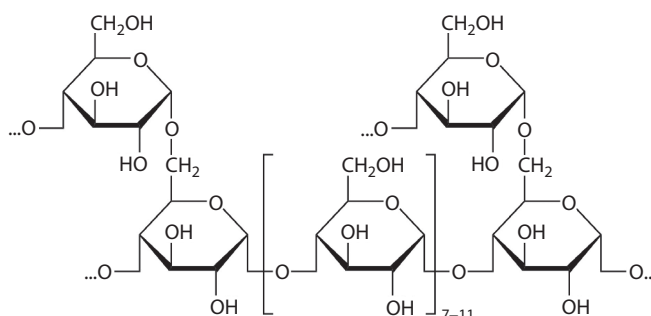


Figure G.56 Glycogen.

Glycosaminoglycan (GAG)

[biomedical, chemical] Building block for regenerative scaffolding. Mucopolysaccharides, long unbranched polysaccharide. GAG consists of a repeating disaccharide unit. Disaccharides are linked saccharides such as GLUCOSE, galactose, and fructose. For instance, sucrose has a linked fructose and glucose and maltose has two glucose molecules in a specific molecular configuration.

Glycosidic bond

[chemical] Type of covalent bond. The glycosidic bond specifically refers to bonding CARBOHYDRATE groups to other chemical groups or MACROMOLECULES. One specific example of chemical bonds of this nature are found in saccharides. More specifically, the bond between amino groups and carbohydrates or similar nitrogen-based chemical groups covalently bonding with carbohydrate molecules.

Goddard, Robert Hutchings (1882–1945)

[general, mechanics] Scientist from the United States, best known for his pioneering efforts on rocket design and rocket launch. In 1935, Goddard performed feasibility with rockets having 889.6 *N* trust force. Goddard faced much RESISTANCE against his attempted space flight program based on the common misconception that the rocket would “push” against an AETHER for propulsion (and space is a VACUUM), instead of the correct philosophy that the combustion in a JET is providing an impulse that obeys the CONSERVATION LAWS, granting a forward MOTION with respect to the open-ended exhaust, in the opposite direction. Goddard is considered the father of modern space travel. Goddard applied a combination of mechanisms to control the flight of the rockets, consisting of gyroscopes, three-axis control, and thruster jets at strategically placed location (see [Figure G.57](#)).



Figure G.57 Robert Hutchings Goddard (1882–1945) on US postal stamp.

Goeppert-Mayer, Maria (Göppert) (1906–1972)

[electromagnetism, general, nuclear] Scientist from Germany (location is currently Poland). Nobel laureate (1963) for her contribution to the description of the electron SHELL MODEL of the ATOM. Maria shared her Nobel Prize with JOHANNES HANS DANIEL JENSEN (1907–1973). Dr. Goeppert-Mayer pioneered the investigations of the double QUANTUM emission phenomenon. She also experimentally verified the phenomenon of double beta DECAY. Maria Goeppert-Mayer was also the first to study the influence of magnetic susceptibility on the index of REFRACTION (also known as refractive index) of specific gasses, with her collaborator KARL FERDINAND HERZFELD (1892–1978) (see [Figure G.58](#)).



Figure G.58 Maria Goeppert-Mayer (1906–1972). (Courtesy of University of Chicago Photographic Archive, [apf1-04167], Special Collections Research Center, University of Chicago Library, Chicago, IL.)

Goldman, David E. (1910–1998)

[biomedical, chemical, energy] Scientist from the United States. Goldman developed the description of the electrochemical potential of the cellular MEMBRANE, based on the work of WALTHER HERMANN NERNST (1864–1941) (see [Figure G.59](#)).



Figure G.59 David E. Goldman (1910–1998). (Reproduced with permission from *Journal of the Acoustical Society of America*, 106[3], 1999 Obituaries. Copyright 1999, Acoustical Society of America.)

Goldman (voltage) equation

[biomedical, chemical, energy] Electrical potential across biological CELL MEMBRANE (i.e., MEMBRANE POTENTIAL: V_m) based on differences in ionic concentrations on either side. For example, assume that only the following ions are allowed to FLOW through the MEMBRANE of a biological cell: POTASSIUM (K^+), SODIUM (Na^+), and chlorine (Cl^-), with respective concentrations $[K^+]$, $[Na^+]$, and $[Cl^-]$. The transmembrane RESTING POTENTIAL is based on the NERNST EQUATION. The derived Goldman potential includes multiple ions and the respective ability of migration through the ION CHANNELS and GAP JUNCTIONS, indicated by the respective permeability for each ION: P_{ion} , expressed as: $V_m = (RT/F_{Far}) \ln \left\{ (P_{Na}[Na^+]_{out} + P_K[K^+]_{out} + P_{Cl}[Cl^-]_{in}) / (P_{Na}[Na^+]_{in} + P_K[K^+]_{in} + P_{Cl}[Cl^-]_{out}) \right\}$, where $F_{Far} = 96,485 \text{ C/mol}$ is the FARADAY CONSTANT, $R = 8.314462175 \text{ J/Kmol}$ the universal GAS constant, and T the temperature during the process. The Goldman potential describes a static PHASE, where the dynamic configuration describes the ACTION POTENTIAL formulated by SIR ALAN LLOYD HODGKIN (1914–1998) and SIR ANDREW FIELDING HUXLEY (1917–2012). In this equation is the permeability constant for the Na^+ ion. A typical value for the resting potential is -90 mV . It is negative because cells are more negative relative to the surrounding medium. Cells that are excitable have the ability to rapidly reverse the potential, causing it to be slightly positive. The potential that is generated in this process is known as the action potential.

Goldman–Hodgkin–Katz equation

[biomedical] See GOLDMAN EQUATION.

Goldstein, Eugen (1850–1930)

[atomic, nuclear] Physicist from Poland/Germany, who worked on the first model of GAS discharge tubes in the investigation of CATHODE and ANODE rays. Goldstein's work lead to the discovery of the PROTON. His interpretation of the rays emitted from the anode was "Kanalstrahlen," specifically based on the fact that his investigational device used a perforated disk as anode, as well as for the cathode. The gas in the sealed tube is ionized on contact with the surface of the holes of the perforations of the anode and hence the PHASE "canal ray" was coined (see [Figure G.60](#)).

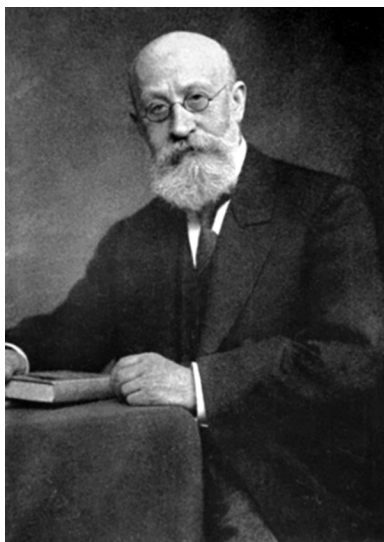


Figure G.60 Eugene Goldstein (1850–1930). (Courtesy of Bettmann/CORBIS.)

Golf ball

[computational, fluid dynamics, mechanics] Aerodynamically designed ball that can be steered with great accuracy resulting from a single stroke. The **TURBULENCE** induced by the dimples on the surface of the ball provide an increase in **DRAG**. Combining the rotation of the ball with the turbulent **BOUNDARY LAYER** provides a **LIFT** that more than compensates for the increase in **FRICTION**. The resulting increase in upward force will promote a greater **DISTANCE** of flight. The dimples thus enhance the **MAGNUS LIFT**. The wedge shape of the golf club generally ensures that the rotation of the ball is in the direction of **MOTION** on the bottom, thus creating a greater pressure on the bottom (according to Bernoulli's law; **DANIEL BERNOULLI** [1700–1782]) and lower pressure on the top with the surface moving in the same direction. When the velocity of the golf ball reaches a threshold (i.e., **REYNOLDS NUMBER** $Re < 2300$) and when slowing down the **FLOW** suddenly becomes laminar. The **LAMINAR FLOW** will detach from the surface that moves in the direction of flow (which goes laminar prior to the opposite side that move against the flow), which will be the top. The break-away laminar part of the flow on the top will result in a negative Magnus lift force, resulting in a rapidly declining trajectory. The concept of the impact of the dimples on the golf ball was realized in the early nineteenth century, by a professor at St. Andrews University in Scotland. Note that for an airplane the laminar flow is more desirable (see [Figure G.61](#)).

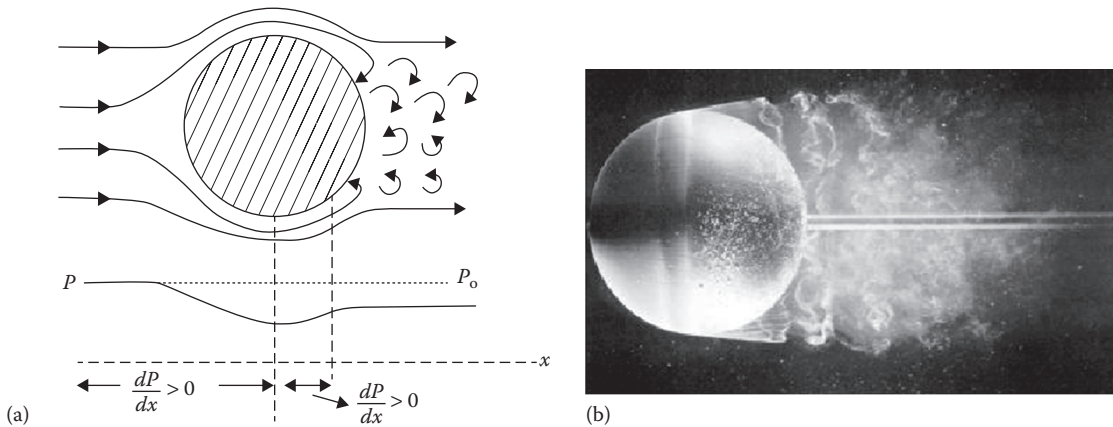


Figure G.61 (a,b) Fluid dynamic aspect of the golf ball in flight.

Goudsmit, Samuel Abraham (1902–1978)

[atomic, nuclear] Scientist from the Netherlands who introduced the concept of ELECTRON SPIN in 1925, simultaneously but independently from GEORGE UHLENBECK (1900–1988) while working under PAUL EHRENFEST (1880–1933), based on the description of the four QUANTUM numbers associated with the electron introduced by WOLFGANG PAULI (1900–1958) (see [Figure G.62](#)).

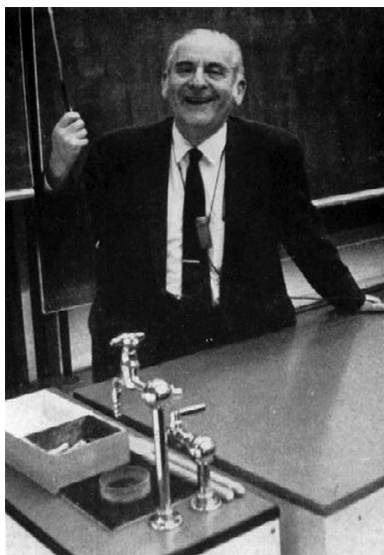


Figure G.62 Samuel Abraham Goudsmit (1902–1978). (Courtesy of Nederlands Tijdschrift voor Natuurkunde.)

Gould, Gordon (1920–2005)

[optics] American physicist attributed to the invention of the laser (acronym for light amplification by STIMULATED EMISSION OF RADIATION), however not universally accepted, since there still remains controversy with the work by Theodore Maiman (1927–2007) (see [Figure G.63](#)).



Figure G.63 Gordon Gould (1920–2005) picture taken in 1940 by his brother Geoffrey Gould.

G-parity

[atomic, nuclear, quantum] QUANTUM NUMBER indicative of the rotation of μ -MESON in isospin space around the two axis which culminates in CHARGE CONJUGATION. The G-parity follows from the generalization of C-parity applied to multiple clusters of particles, resulting in a concise quantum number resulting from multiplication of associated quantum numbers. The value of G-parity is defined as $G_{\text{par}} = Ce^{i\pi I_2}$, where C is a constant related to the C-parity (i.e., C-parity operator), and I_2 is the second component of the isospin of the NUCLEON. The elementary PARTICLE mesons have a specific PARITY referred to as G-parity.

Graded index of refraction—lens

[optics] LENS that relies on the gradual or discrete changes in index of REFRACTION to provide focusing action, also known as GRIN lens. The GRIN lens does not necessarily require curvature to focus. GRIN lens design is often applied to fiber-optics to center the optical information for maximum efficiency in ray transfer.

Graf's addition theorem

[acoustics, computational] Bessel function summation algorithm, expressing the Bessel function: $C_v(\eta r_j)e^{iv(\theta_j - \vartheta_{j\ell})}$, in POLAR COORDINATES (r_j, θ_j) , as a series of two functions in respective coordinate systems with respect to each other. Each coordinate system has an origin: O_ℓ and O_j , where O_ℓ can be placed with respect to O_j in coordinates $(R_{j\ell}, \vartheta_{j\ell})$. The function C_v can in this case be represented by any of the BESSEL FUNCTIONS (zeroth-order, first-order and second-order): $J_v, I_v, Y_v, K_v, H_v^{(1)}$, and $H_v^{(2)}$. The representation is as the following recursive relations: $C_v(\eta r_j)e^{iv(\theta_j - \vartheta_{j\ell})} = \sum_{\mu=-\infty}^{\infty} C_{v+\mu}(\eta R_{j\ell})J_\mu(\eta r_\ell)e^{i\mu(\pi - \theta_\ell - \vartheta_{j\ell})}$ under the condition that $j \neq \ell$; as well as $H_v^{(1)}(\eta r_j)e^{iv(\theta_j - \vartheta_{j\ell})} = \sum_{\mu=-\infty}^{\infty} H_{v+\mu}^{(1)}(\eta R_{j\ell})J_\mu(\eta r_\ell)e^{i\mu(\pi - \theta_\ell - \vartheta_{j\ell})}$, and $K_v(\eta r_j)e^{iv(\theta_j - \vartheta_{j\ell})} = \sum_{\mu=-\infty}^{\infty} K_{v+\mu}(\eta R_{j\ell})I_\mu(\eta r_\ell)e^{i\mu(\pi - \theta_\ell - \vartheta_{j\ell})}$ under the same boundary condition.

Graham, Thomas (1805–1861)

[biomedical, chemical] Chemist from Great Britain (Scotland) and physical scientist. Graham was a pioneer in dialysis and made significant contributions to the theoretical description of GAS DIFFUSION. In dialysis, colloids (MICROSCOPIC solutes, or suspension) are separated from dissolved molecules or ions (crystalloids) by means of chemical gradients and the inherent differences in diffusion rates across a SEMIPERMEABLE MEMBRANE. Graham is also called the father of colloid chemistry (see [Figure G.64](#)).

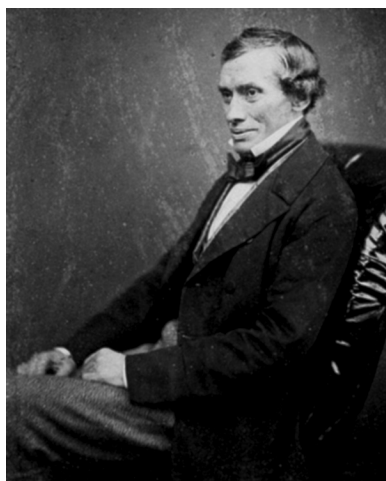


Figure G.64 Thomas Graham (1805–1861) by Maull & Polyblank, 1856.

Graham's law of diffusion

[biomedical, chemical] GAS DIFFUSION expression defined by THOMAS GRAHAM (1805–1861) in 1833. The rate of gas diffusion is inversely proportional to the square root of the MOLECULAR WEIGHT (MW) of the substance (e.g., SOLUTE): $D_{\text{diff}} \sim MW^{-(1/2)}$.

Grain boundary

[acoustics, optics, solid-state] The mismatch in surface junction mating two separate crystal structures. Crystals with different direction can be joined as a result of ANNEALING or they can be grown as such. In vertical direction this type of discontinuities are classified as “staging faults.”

Gram (g)

[general] Unit of mass, whereas weight is a function of GRAVITATIONAL ACCELERATION. Mass is a QUANTIFICATION of the amount of MATTER in an object. Even though the gram is elementary, the use of the KILOGRAM (kg) is the international standard. The mass of a platinum–iridium cylinder (height = 39 mm; diameter = 39 m), held at the INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES is the recognized standard for 1 kg. A set of 40 virtually identical cylinders (slight errors in reproduction, even though the dimensions can be verified with extremely high degree of accuracy, on a wavelength basis) were produced and distributed to regional calibration stations (in the United States the National Institute of Standards and Technology in Boulder, Colorado). Due to the inherent difficulties associated with measuring the mass of a single ATOM this has still not evolved into a easily reproducible measure and remains the only artificial standard.

Gram atomic weight

[atomic, nuclear] The relative atomic weight of an ELEMENT, expressed in grams.

Gram mole

[general, thermodynamics] The quantity of a substance containing the equivalent number of components (atoms/molecules) to the 12 g mass of carbon 12 (^{12}C); a mol of ELEMENT, containing Avogadro's number in molecules: $N_a = 6.022 \times 10^{23}$ molecules/mol.

Gram molecular mass (gram formula)

[atomic, nuclear] The mass of a volume of GAS at $22.4 \text{ L} = 0.0224 \text{ m}^3$ will measure a mass in grams that equals the molecular mass for the ELEMENT, all at standard temperature ($0^\circ\text{C} = 273.15 \text{ K}$) and standard pressure ($1 \text{ atm} = 101.325 \text{ kPa}$).

Gram molecular weight (gram mole)

[nuclear] The relative molecular weight of a compound, expressed in grams.

Gramme, Zénobe-Théophile (1826–1901)

[energy, general] Engineer from Belgium, inventor of the electric GENERATOR (see [Figure G.66](#)).



Figure G.66 Zénobe-Théophile Gramme (1826–1901).

Gramme dynamo

[energy, general] Early concept electrical current GENERATOR designed by the French engineer ZÉNOBE-THÉOPHILE GRAMME (1826–1901) in late 1860s. The electric motor (invented by WILLIAM STURGEON [1783–1850] in 1832) and the dynamo were developed independent from each other and in 1873 at an exposition in Vienna, Austria, both devices were simultaneously displayed, while the dynamo was accidentally wired wrong and became a MOTOR. The GRAMME DYNAMO was originally driven by a steam ENGINE to create ELECTRICITY (see [Figure G.65](#)).

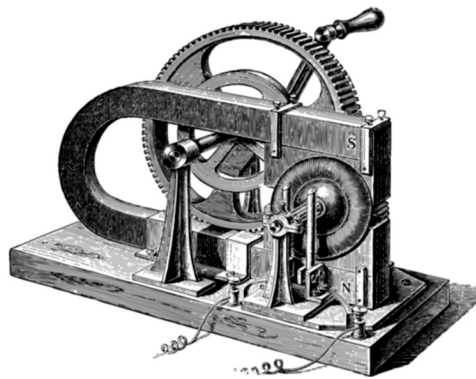


Figure G.65 Gramme Dynamo.

Grand unification theories (GUTs)

[computational, general, quantum] Also referred to as GRAND UNIFIED THEORY, (see [SCHRIEFER UNIFIED THEORY](#)).

Grand unified theory

[computational, general, quantum] See [SCHRIEFER UNIFIED THEORY](#).

Grashof, Franz (1826–1893)

[fluid dynamics, thermodynamics] German mechanical engineer, introduced the concept of the Grashof number for scaling free convection. Additional work by Grashof was in free convection and the FLOW of steam in relation to steam engines and steam generators as well as mechanical quality control for MACHINES (see [Figure G.67](#)).



Figure G.67 Franz Grashof (1826–1893), around 1870.

Grashof number ($Gr = (g\beta\rho^2(T_s - T_\infty)L^3)/\eta_{kin}^2$)

[biomedical, fluid dynamics, geophysics, thermodynamics] Dimensionless number showing the proportional factor between buoyant force and the net viscous force, where β is the linear EXPANSION coefficient, g the GRAVITATIONAL ACCELERATION, ρ density, T_s the surface temperature, T_∞ the main body of LIQUID temperature, L the characteristic length of the object, and η_{kin} is the KINEMATIC VISCOSITY. The Grashof number is particularly important in FLUID flow containing NATURAL CONVECTION. The Grashof number describes the conditions for turbulent versus LAMINAR FLOW, where at low Grashof number the FLOW is laminar, the transition from laminar to turbulent flow occurs from $10^8 < Gr < 10^9$ beyond which the flow is fully turbulent, specifically for natural convection involving vertical flat plates. The multiplication of the Grashof number by the PRANDTL NUMBER yields the RAYLEIGH NUMBER. For mass transfer there is an equivalent Grashof number describing the natural convection, the mass transfer Grashof number (Gr_m), see GRASHOF NUMBER, MASS TRANSFER.

Grashof number, mass transfer ($Gr_m = -(1/\rho)(\partial\rho/\partial[a])_{T,P}(g([a]_s - [a]_a)L^3/\eta_{kin}^2)$)

[fluid dynamics, thermodynamics] Dimensionless number describing the quotient of the mass transfer over the viscous force, where $[a]$ is the concentration of constituent “a,” $[a]_s$ the concentration of “a” at the surface, $[a]_a$ the ambient environment concentration of species “a,” g the GRAVITATIONAL ACCELERATION, ρ density, L the characteristic length of the object, η_{kin} is the KINEMATIC VISCOSITY, and T and P represent that the derivative is made under constant temperature and constant pressure, respectively.

Grating

[atomic, general, nuclear] See **DIFFRACTION GRATING**.

Grating, flow of a liquid through a

[fluid dynamics] Viscous FLOW through a mechanical GRATING or LATTICE (e.g., square array or lattice of cylinders) that produces a specific flow pattern of wave INTERFERENCE. Viscous flow of a LIQUID perpendicular to a line (or “grating”) of identical cylinders that are evenly spaced can provide a scenario that can be described by “lubrication theory” when the spacing between the cylinders is significantly smaller than the CROSS SECTION of the respective cylinders. The pressure drop and the associated force of the respective cylinders can be derived for various configurations.

Grating, reflection and transmission of sound waves by a

[fluid dynamics] In ACOUSTICS just as much as in OPTICS a “RESONANCE” pattern can be defined based on the width (b_{gap}) and spacing (d_{gap}) between openings in a plate where SOUND with WAVE number $k = 2\pi/\lambda$, with wavelength λ for a system in one, two, or three dimensions can be defined to have maximum INTERFERENCE at spacings λ_{space} to be $\lambda_{\text{space}} = \{(4s_i^2\pi^2/(b_{\text{gap}} + d_{\text{gap}})) - k^2\}^{1/2}$, where s_i is different for the three dimensional configurations; in one dimension $s_1 = \tau/2v_s \{(t - (x/v_s))^2 + \tau^2\}^{-1}$ with location x ; in two dimensions: $s_2 = \sqrt{[v_s r/r] \{\sin((\pi/4) - (3/2)\xi) \cos^{3/2} \xi\} (4\sqrt{2v_s^2 r^2})^{-1}}$ where ξ follows indirectly from $t = (r/v_s) + r \tan \xi$; and in three dimensions: $s_3 = (\tau/2\pi v_s^2)((r/v_s) - t) [2\{(t - (x/v_s))^2 + \tau^2\}^2]^{-1}$, location r , where τ_{period} is the time constant over which the phenomenon is observed, and v_s the speed of sound for the medium.

Grating equation

[general] The formation of INTERFERENCE lines as the result of light projected on a DIFFRACTION GRATING with line separation d_{line} , operating under illumination at wavelength λ , creating several orders of maxima, starting directly on the optical axis with $m = 0$ and subsequent maxima ($m = 0, \pm 1, \pm 2, \dots$), where the ANGLE of the order of the maximum is θ_m defined as $d_{\text{line}} \sin \theta_m = m\lambda$. The first documented use of a diffraction GRATING was by JOSEPH VON FRAUNHOFER (1787–1826) in 1823. A diffraction grit with n slits, separated by DISTANCE d and width b (diffraction constant) produces a radiant intensity profile (i.e., radiance measured electronically I) as a function of the angle with the normal (θ) with the diffraction plate expressed as $I = I_0 (\sin n\alpha'/\sin \alpha') (\sin \beta'/\beta')$, where I_0 is the incident MAGNITUDE of radiance, $\alpha' = (\pi d_{\text{line}} \sin \theta)/\lambda$, and $\beta' = (\pi b \sin \theta)/\lambda$. For nonnormal incidence (at angle θ_i) the respective ($m = 0, 1, 2, \dots$) principal maxima will fall in the following directions: $m\lambda = d_{\text{line}} (\sin \theta_i + \sin \theta_m)$.

Grating space of crystals

[atomic, electromagnetism, nuclear] Crystal structure diffraction based on REFLECTION, in comparison to optical transmission diffraction from a plate with lines (DIFFRACTION GRATING). In X-RAY diffraction, the GRATING used is a crystal with a highly regular crystal spacing, identified by the DISTANCE between crystal planes (d_{plane}) yielding the angular distribution of the respective maxima as $2d_{\text{plane}} \sin \theta_{\text{Bragg}} = m\lambda$, where θ_{Bragg} is the Bragg ANGLE (i.e., angle of incidence) for the crystal, X-ray wavelength λ , and order of maximum $m = 1, 2, \dots$. The distribution of the maxima is known as Bragg's law. This mechanism is used to analyze the structure of crystals.

Grätz, Leo (1825–1941; “Graetz”)

[fluid dynamics, thermodynamics] Physicist and mathematician from the Prussian Empire (now Germany) involved in electromagnetic WAVE propagation, contemporary of HEINRICH HERTZ (1847–1894) and

WILLIAM RÖNTGEN (1845–1923). In addition to electromagnetic dispersal his work included FRICTION and ELASTICITY as well as heat conduction (see Figure G.68).



Figure G.68 Leo Grätz (1825–1941) painted by Franz von Stuck (1906).

Grätz number ($Gz = \dot{m}c_p/kL = (L/d)(\kappa/(d \times v\rho c_p)) = (L/d)(\alpha_{th}/(d \times v))$)

[biomedical, fluid dynamics, geophysics, thermodynamics] Dimensionless number representing the ratio of thermal capacity with respect to convective HEAT TRANSFER, where c_p is the heat capacity, $\dot{m}$ the mass flow rate of the FLUID, κ the THERMAL CONDUCTIVITY, L the characteristic length of the object, d the FLOW diameter, ρ density, v velocity, and α_{th} the thermal DIFFUSIVITY. The Grätz number applies in particular to heat transfer under general flow conditions and in LAMINAR FLOW the convection phenomenon in particular. In biomedical applications, there are several configurations of the flow diagram involving many odd and contorted bi- and trifurcation splits reducing or increasing in vessel diameter. In addition, the pulsatile character will generate flow patterns that will have opposing direction from WALL to center of flow. In the CAPILLARY beds (arterioles, capillaries, and venules), the Grätz number is generally less than 0.4, whereas in the arterial and venous system $Gz > 10$. With these Grätz numbers as a reference the capillary bed will have an intense heat exchange, while in the tissue surrounding the veins and arteries negligible heat exchange will take place, with congruent insignificant drop in BLOOD temperature over the course of the flow. In GEOPHYSICS applications, the Grätz number can be used, for instance, to determine the extent of lava flow, where a high Grätz number (e.g., $Gz > 230$) pertains to a fast, wide, short, and thick flow of lava which is seemingly unstoppable with little intention to cool down due to heat exchange with its environment, whereas slow, long, and thin lava flow with low Grätz number will be expected to stop and solidify.

Gravimeter

[general, geophysics] Instrument used to measure the gravitational force as a function of location. The gravitational attraction is a function of the local density and material structure of the EARTH to extensive depths. The gravimeter can provide indications of mineral formations and fossil fuel pockets due to their specific material properties and volumetric presence.

Gravitation

[general, geophysics] Physical attraction force (F_G) between two object based on their respective masses; large mass (M) versus small mass (m), separated at DISTANCE from respective centers of mass (r): $F_G = G(mM/r^2)$, where G is the gravitational constant. It is also known as Newton's LAW OF UNIVERSAL GRAVITATION (see [Figure G.69](#)).



Figure G.69 Influence of gravity.

Gravitational acceleration

[general, mechanics, thermodynamics] The continuous increase in velocity of an object moving under the influence of attraction from another object with mass, where GRAVITY is the only force involved. Phenomenon first described by Strato of Lampsacus (c. 335–289 BC) from his observations of streaming rainwater running down a roof, starting out in LAMINAR FLOW and gradually developing an erratic flow pattern, TURBULENCE. The gravitational acceleration is a function of LATITUDE and altitude. The acceleration ($g = d^2r/dt^2$) of any object (irrespective of mass or shape and size) under the influence of gravitational force as a function of the mass of the object (M) exerting the gravitational pull at a DISTANCE from the CENTER OF GRAVITY (r) multiplied by the gravitational constant expressed as: $d^2r/dt^2 = G(M/r^2)$. In reality, the true acceleration (a) will be subject to other external forces, such as FLUID DRAG ($\Sigma F = ma$) (also see GRAVITY).

Gravitational constant (G)

[general] In Newtonian PHYSICS, the acceleration ($a = d^2r/dt^2$) of an object under the influence of GRAVITY is a function of the mass of the object (M) exerting the gravitational pull at a DISTANCE from the CENTER OF GRAVITY (r) multiplied by the gravitational constant expressed as: $d^2r/dt^2 = G(M/r^2)$.

Gravitational energy

[general] See GRAVITATIONAL POTENTIAL ENERGY.

Gravitational field

[general] Theoretical field of influence exerted by an object with mass. The definition assumes the exchange of massless particles across a DISTANCE that exchange the gravitational force in similarity with electroforce resulting from free and “bound” charges (see COULOMB LAW). The gravitational attraction force has a

MAGNITUDE and direction that can be measured for instance with the GRAVIMETER. The units for the magnitude of the gravitational field are 10^{-2} m/s^2 . For the NORTH American landmass, the gravitational field is weakest in the peaks of the Rocky Mountains and strongest in the Atlantic basin, specifically off the continental shelf (*see* G) (*see* Figure G.70).

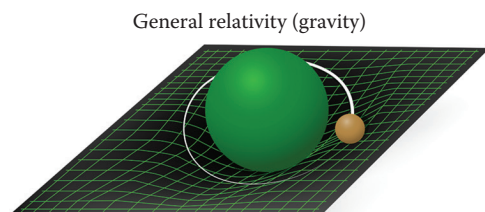


Figure G.70 Gravity in the two-dimensional fabric of space, where space acts as a sheet on which celestial objects are spread out and make an indentation representative of their gravitational attraction.

Gravitational potential energy (PEG: U)

[general] ENERGY of a MASS (m) resulting from the gravitational attraction due to the DISTANCE (h) from the center of mass of the “attracting” object with exerted GRAVITATIONAL ACCELERATION (g): $U = mgh$.

Gravitational waves

[astrophysics, general, geophysics, mechanics, relativistic] Propagation of gravitational disturbance from a point of origin. This phenomenon is predicted under EINSTEIN’S THEORY OF GENERAL RELATIVITY. Examples are the GRAVITATIONAL FIELD of a double STAR that rotates and generates a stable OSCILLATION, whereas an exploding star (e.g., SUPERNOVA) will have an instantaneous and nonreproducible fluctuation in the gravitational attraction influence span (*also see* TIME PERTURBATION). Ripples in the space–time CONTINUUM. GRAVITY, according to Einstein’s GENERAL THEORY OF RELATIVITY, is how mass deforms the fabric of space. In the proximity of any body with mass, the shape of space turns into curved array. There is still no conclusive statement about the extent and “mechanism of action” with regard to the extended reach (in DISTANCE to the mass) of GRAVITATION at this time (*also see* STRING THEORY). Apparently, this spatial curving does not always remain only in the proximity of the massive body. Einstein hypothesized that this deformation can propagate throughout the GALAXY, similar to the propagation of SEISMIC waves in the EARTH’S CRUST; captured partially by the EINSTEIN EQUATIONS. Gravitational waves will travel through the “empty” UNIVERSE, unlike seismic waves, propagating at the speed of light. Next to the gravitational waves that are linked to the theoretical formation model for the creation of the universe described by “inflation” process following the “Big Bang,” additional gravitational waves are observed in association with black holes. The rotation of the incursion disk surrounding a BLACK HOLE, and the potential PRECESSION of the helical MAGNETIC FIELD emerging from the core of the incursion disk in perpendicular direction are theoretically showing the potential to generate gravitational WAVE twists, which propagate similar to the movement of giant whip. The helical magnetic field will interact with charged particles (i.e., ions) to become coiled into a helix-shaped pattern. The helix of charged particles is ejected in the direction perpendicular to the incursion disk at speeds approaching the speed of light. Note that the MOTION of the charged particles also generates an electric field. The electric and magnetic field from both the black hole and the ION JET generate an additional force on the moving particles, influencing the trajectory, bending away from the central axis, forming a whip-action pattern. The trajectory of the PARTICLE jet can change direction, even change back-and-forth. This changing motion generally takes place in a period scale ranging from thousands to millions of years, but can be detected with a RESOLUTION of months or weeks. The gravitational waves are in the direction perpendicular to the incursion disk. These gravitational waves are also known as Aflvén waves. The Aflvén waves appear to migrate at speeds just slower than the speed of light. Gravitational waves were predicted by ALBERT EINSTEIN (1878–1955) in 1916.

Gravitational waves are verified based on observations made under the Background Imaging of Cosmic Extragalactic POLARIZATION experiment, such as performed in locations as the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO, founded 1992), Livingston, Louisiana and more pronounced, at the South Pole. The gravitational waves are derived from observation made by radiotelescopes, detecting a broad spectrum of ELECTROMAGNETIC RADIATION and associated DOPPLER shifts in specific spectral signatures resolved by interferometric techniques. Inflation theory, which was first proposed in 1979, states that the universe, originally chaotic quantum NOISE made of unstable particles and space–time TURBULENCE, expanded at an unimaginable rate, creating these gravitational waves, smoothing out the chaos, and leaving the orderly cosmos we see today. Additional gravitation waves can be linked to the collision of black holes, and the potential FUSION of the respective black holes into one. The periodic changing with respect to the gravitational WAVE concept are linked to the scaling of the systems involved, and can range from microseconds to millions of years. In theoretical analyses, the gravitational wave concept is subdivided into four ranges: (1) high-frequency regime (microsecond scale) potentially associated with COLLIDING BLACK HOLES, creating ripples in time; (2) the low-frequency regime, has not yet been confirmed, not associated with physical phenomena and is derived from PHASE shifts detected in the MICROWAVE RADIATION from galactic background emissions.; (3) the very-low frequency regime (period in the order of months and several years) is measured and detected based on PULSAR stars and black hole mechanism of action principles; (4) the ultra-low frequency regime (millions of years) is associated with the ENERGY release of a theoretical phenomenon, such as described by, for instance, the theoretical “Big Bang” concept. The effect of the “Big Bang” with respect to gravitational waves are captured by a concept proposed in 1979, “inflation theory.” Inflation theory states that the universe expanded from a chaotic QUANTUM noise, consisting of unstable particles and space–time turbulence at an unimaginable rate, generating gravitational waves in the process. This process could be thought of as resembling a MACH WAVE in the ACOUSTICS domain. This chaotic energy balance subsequently was prone to a damped OSCILLATION process, rendering an orderly cosmos after extinction of the wave (with presumed oscillatory period of millions of years). The ultra-low frequency regime so far has not been confirmed since it requires several decades and centuries worth of data collection. The perturbation process can be described in various ways, based on the assumption made regarding the boundary conditions. The four prevailing mechanisms are, according to their presumed relevance, (1) Isaacson shortwave approximation; (2) small perturbation in flat space; (3) linearization to the Isaacson shortwave approximation with respect to the Einstein equations; (4) gauge condition, referred to as Donder gauge or Lorentz gauge, also found as “harmonic gauge” and Hilbert gauge. A theoretical SOLUTION for Einstein’s equations with respect to a nonrotating black hole was derived under severely limiting boundary conditions by KARL SCHWARZSCHILD (1873–1916) in 1915, however generally a computer is required to perform the required NUMERICAL analyses (see [Figure G.71](#)).

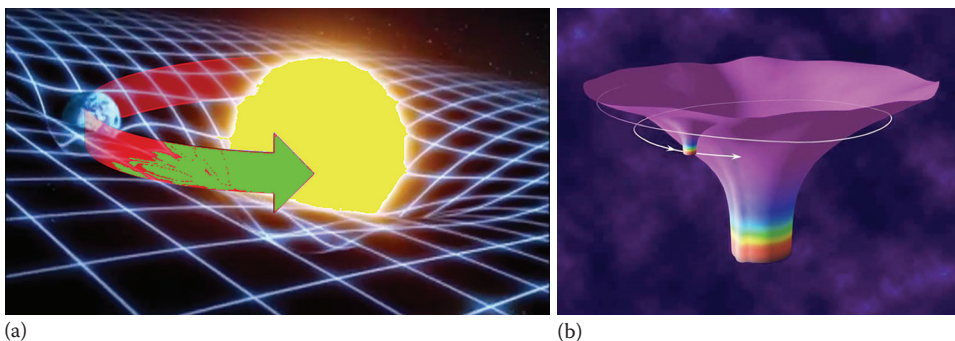
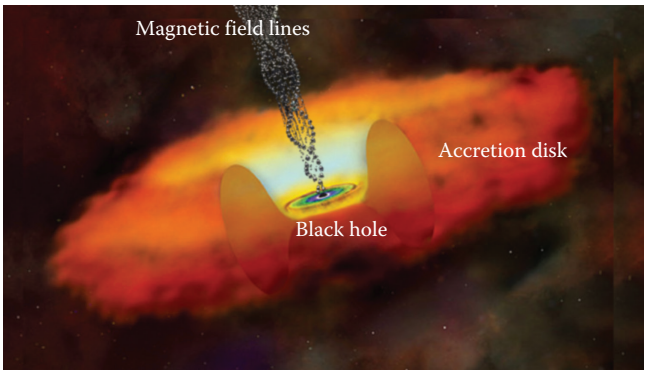
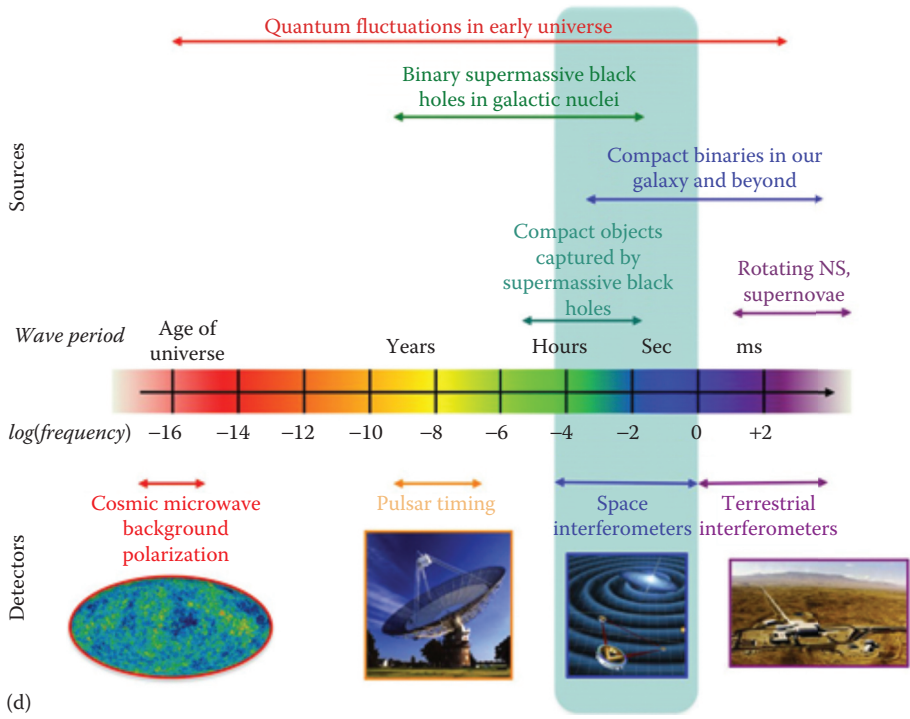


Figure G.71 (a) Graphical representation of the curvature of space in the gravitational model. (b) An artist's impression of the space–time “geometry” in the event of an extreme mass ratio in spiral, representing a smaller black hole orbiting around a supermassive black hole. (Courtesy of NASA.) (Continued)



(c)



(d)

Figure G.71 (Continued) (c) Artist's impression of RGG 118 in which a black hole is surrounded by an accretion disk consisting of hot gas, with a torus consisting of dust and cooler gas. The light blue ring on the rear side of the torus is the predicted fluorescence resulting from iron atoms, which are excited by X-rays emitted from the hot gas torus. (Courtesy of NASA/CXC/M.Weiss.) Graphical representation of the accretion disk surrounding a black hole and perpendicularly emerging "magnetic field." (d) The gravitational wave spectrum, sources, and detectors. (Courtesy of NASA.) (Continued)



(e)

Figure G.71 (Continued) (e) LISA Pathfinder, launched 2015. Laser Interferometer Gravitational wave. BICEP2 (Background Imaging of Cosmic Extragalactic Polarization). (Courtesy of European Space Agency [ESA]/Astrium/IABG, Paris, France.)

Graviton

[computational, energy, general, nuclear, quantum, relativistic, thermodynamics] Virtual PARTICLE that has been theoretically deduced in QUANTUM FIELD THEORY that represent the QUANTUM of the GRAVITATIONAL FIELD. The graviton mediates the GRAVITATIONAL FORCE, as part of the ELEMENTARY PARTICLES and FOUR BASIC FORCES. The graviton is a hypothetical MASSLESS, UNCHARGED particle that travels with the SPEED OF LIGHT and has presumably infinite range. Based on ALBERT EINSTEIN's (1879–1955) SPECIAL THEORY OF RELATIVITY, masses trapped in a GRAVITATIONAL FIELD that are accelerating should radiate GRAVITATIONAL WAVES, similar to accelerated charges emitting ELECTROMAGNETIC RADIATION. The graviton has spin 2 expressed in Planck's constant for SPIN: $\hbar$, as $\hbar = \hbar/2\pi$. In this configuration the particle obeys the BOSE–EINSTEIN STATISTICS.

Gravity

[geophysics, mechanics] (syn.:) {use: planetary objects ORBITS, PLANET, comet} The earth's terrestrial gravitational pull is influenced by the fact that the EARTH is rotating and as such expanding at the equator and compressed between the two POLES. The attraction between objects was described by ISAAC NEWTON in 1685. In addition, the first documented observation of gravitational attraction between ordinary objects was made in 1798 by HENRY CAVENDISH (1731–1810). The ABSOLUTE GRAVITATIONAL ACCELERATION g_o at any location on the planet, and for that MATTER of any object, is a linear function of the mass of the object M and inversely proportional to the local radial DISTANCE from the center point of the core to a point of relevance outside the mass (r) squared: $g_o = G(M/r^2)$, where $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$ is the universal gravitational constant. Compensating for the earth's rotational velocity at the equator (v_E) and distance to the core (R_E) gives the corrected weight as a function of location with respect to the equator as: $W_{\text{corr}} = m(g - (v_E^2/R_E))$. See G (also see GRAVIATION).

Gravity, acceleration due to (g)

[general] Gravitational acceleration at various latitudes at sea level.

LATITUDE	GRAVITATIONAL ACCELERATION: G (M/S ²)
0°	9.7804
15°	9.7838
30°	9.7933
45°	9.8062
60°	9.8192
75°	9.8287
90°	9.8322

Gravity, Kepler’s laws

[general] See KEPLER’S LAW.

Gray, Stephen (1666–1736)

[electronics, general] Scientist and astronomer from the United Kingdom/Great Britain who discovered the difference between conductors and nonconductors with the newly discovered availability of electric current in 1729 (also see RESISTANCE) (see Figure G.72).



Figure G.72 Stephen Gray (1666–1736).

Green, George (1793–1841)

[computational] Mathematician from Great Britain. Green is known for his methods of solving differential equations with complex number basis. Green also introduced the concept of POTENTIAL FUNCTION.

The theoretical work by George Green also included a mathematical description of ELECTRICITY and MAGNETISM, influencing the work of JAMES CLERK MAXWELL (1831–1879) and CARL FRIEDRICH GAUSS (1777–1855) (see Figure G.73).



Figure G.73 George Green (1793–1841).

Green's function

[acoustics, computational] Mathematical description of the field established from a POINT SOURCE. Note that the field can be electric or magnetic, but also VELOCITY POTENTIAL. SOLUTION method for the determination of electronic ENERGY levels (E) and WAVE FUNCTIONS (Ψ) of a system with respect to the HAMILTONIAN (H) energy expression: $H\Psi = E\Psi$, where the Hamiltonian can often be periodic. The Green's function $G(x, t | x_i, \tau)$ is a family of solutions to linear differential equations. One specific example of a Green's function is the solution to one-dimensional thermal DIFFUSION expressed by the heat equation as: $\alpha(\partial^2 T / \partial x^2) + (\alpha_T / k_T)g(x, t) = \partial T / \partial t$, where $T(x, t_0) = U(x)$, with $t_0 = 0$, and $k_i(\partial T / \partial n_i)_{x_i} + b_i T(x_i, t) = f_i(t)$; $i = 1, 2$. The solution yields:

$$T(x, t) = \int_{x'} G(x, t | x', 0) U(x') dx' + \frac{\alpha}{k} \int_{\tau=0}^t \int_{x'} g(x', \tau) G(x, t | x', \tau) dx' d\tau$$

$$+ \alpha \int_{\tau=0}^t \sum_{i=1}^2 \left\{ \frac{u_i(\tau)}{k_i} G(x, t | x_i, \tau) \right\} d\tau - \alpha \int_{\tau=0}^t \sum_{i=1}^2 \left\{ u_i(\tau) \frac{\partial G(x, t | x_i, \tau)}{\partial n_i} \right\} \bigg|_{x'=x_i} d\tau,$$

where the first term represents the initial conditions and the second term provides the generation of ENERGY. Computational technique applied to an inhomogeneous differential equation describing the approach to solve for an IMPULSE RESPONSE: $f(t) = \delta(t - t')$ (i.e., delta function). The impulse will be limited in time and place

within a spatial domain and well-defined initial conditions. The Green function solution for a point source in $x_i = \xi$ is given by $G(x, t | \xi, \tau) = -\left[a^2/(4\pi(t-\tau))\right]^{3/2} (1/a^2) \exp\left(-(a^2|\vec{r}-\vec{\rho}|/(t-\tau))\right)$ (see Figure G.74).

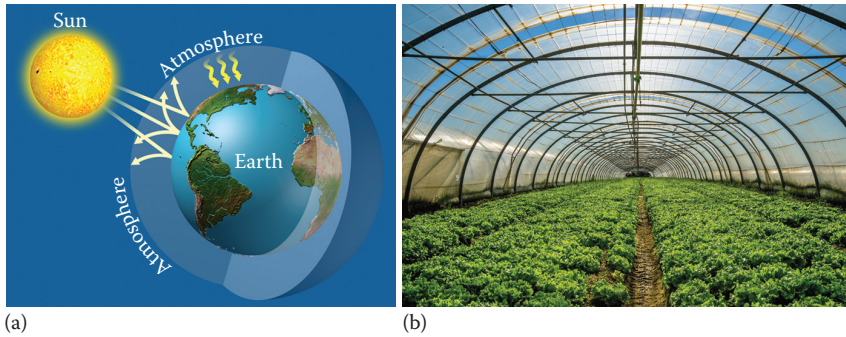


Figure G.74 (a) The atmospheric conditions providing a shell of gasses that reflect the infrared emission from the Earth as a result from the exposure to sunlight, thus retaining a larger quantity of heat close to the earth's surface in comparison to the absence of the reflective gaseous shell and (b) glass greenhouse, confining the heat from the Sun to promote plant growth in geographic locations that may not be ideally suited for the type of plant.

Green's law

[fluid dynamics] Definition used in the description of the WAVE MOTION in a canal with variable outline. Using the EQUATION OF CONTINUITY with respect to the CROSS SECTION of the tidal wave motion ($\mathbb{S}$), this provides for the ordinate of the upward displacement (ψ) of the free surface of the LIQUID medium as a function of location in the direction of FLOW (x): $\psi = -(\mathbb{S}/b)(\partial\xi/\partial x)$, where $\xi = \int u dt$, the time-dependent integral of the surface displacement within the location range past point x with u the average velocity and b the local width of the canal. The equation of continuity for a variable CROSS SECTION is now defined as $\psi = -(1/b)(\partial(\xi\mathbb{S})/\partial x)$. Using the ENERGY content of the wave RIPLE in a riverbed, the AMPLITUDE can be shown to adhere to Green's law: $\psi \propto -(1/\sqrt{b})(1/\sqrt{b})$ (see Figure G.75).

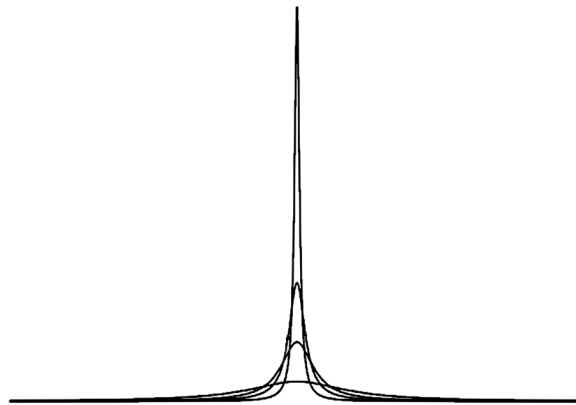


Figure G.75 Greens function limit.

Green's theorem

[fluid dynamics] Calculus theorem relating the integration of a permutation of derivatives (e.g., complex-valued functions from G and U , with both the first and second partial derivatives continuous and single-valued) within a closed surface S (enclosing a volume V) to an integration over a volume. This is formulated with respect to the partial derivative to the normal ($\vec{n}$) in the outward direction ($\partial/\partial n$), expressed as

$\iiint_V (U\nabla^2 G - G\nabla^2 U) dV = -\iint_S (U(\partial G/\partial n) - G(\partial U/\partial n)) dS$, where $\nabla^2 = (d^2/dx^2) + (d^2/dy^2) + (d^2/dz^2)$ is the Laplace operator. This theorem applies, for instance, to diffraction theory, irrotational MOTION, and ELECTROSTATICS.

Greenhouse effect

[geophysics, meteorology, thermodynamics] Gradual global increase in average temperature attributed to the increase in gasses such as CO, CO₂, CH₄, N₂O, and CFC's the latter is used as a propellant in AIR canister-based delivery of cosmetic and industrial spraying aerosols as well as consumer paints. The changes in atmospheric composition are increasing the transmission for broadband ULTRAVIOLET through visible RADIATION, inherently heating the EARTH'S CRUST and water surface. One notable difference is the depletion of the ozone layer, in the lower portion of the STRATOSPHERE, or between the TROPOSPHERE (0–10 km) and the main stratosphere (10–50 km). Additionally, the formation of specific air mass compositions apparently acts as a “blanket,” insulating the natural cooling process of black-body radiation, thus encapsulating the black-body radiation to remain close to the earth's surface (see [Figure G.76](#)).



Figure G.76 Surface wave phenomenon.

Greenwich Meridian

[astronomy, general, geophysics] Starting point for the longitude demarcation running through the city of Greenwich in Great Britain: 0°. It is also referred to as the Prime Meridian (see [Figure G.77](#)).



Figure G.77 Demarcation of the Greenwich Meridian in London near the Greenwich Observatory.

Gregorian telescope

[astronomy/astrophysics, general, optics] REFLECTION telescope concept invented by JAMES GREGORY (1638–1675) in 1661. Gregory was not satisfied with the design, based on the theoretical PROBABILITY of aberrations in shape and COLOR reproduction, and did not finish constructing his invention.

Gregory, James (1638–1675)

[astronomy/astrophysics, general, optics] Scientist and mathematician from Great Britain (Scotland) who invented the REFLECTION telescope in 1661 (i.e., GREGORIAN TELESCOPE). The physical construction of the reflection TELESCOPE was performed after several iterations for aberrations by SIR ISAAC NEWTON (1642–1727) in 1668 (see [Figure G.78](#)).

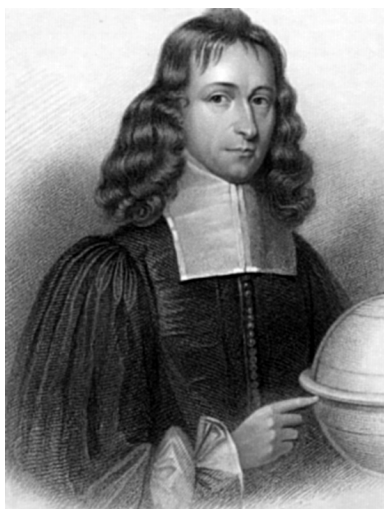


Figure G.78 James Gregory (1638–1675).

Grimaldi, Francesco Maria (1618–1663)

[optics] Jesuit priest from Italy who described the concept of edge diffraction. Grimaldi documented the formation of an IMAGE of a pinhole on a distant WALL to be larger than the pinhole with undefined edge.

He attributed this phenomenon to be akin to the CHRISTIAAN HUYGENS (1629–1695) water-wave phenomenon, in this case for light (see [Figure G.79](#)).



Figure G.79 Francesco Grimaldi (1618–1663).

GRIN

[optics] See GRADED INDEX OF REFRACTION LENS.

Ground

[energy, general] Volume of conduction material with virtually unlimited amount of ELECTRIC CHARGE that can be added to or retrieved from without a significant change in the total net electric charge. As a result of the preservation of “equilibrium,” the ENERGY requirements for the successive electron exchanges will be identical and minimal. Specifically, since more than one component will be connected to this “ground” the depletion and replenishing of free electrons will be interchanging from location to location, providing an average state of equilibrium (see [Figure G.80](#)).

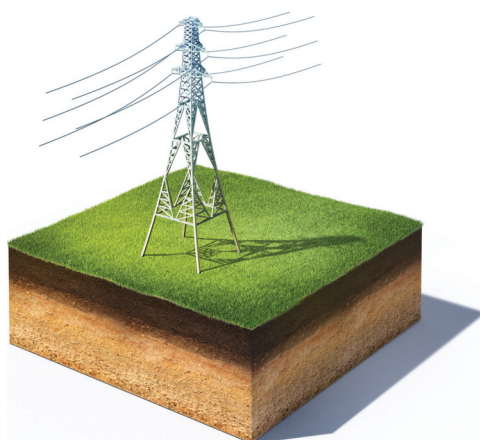


Figure G.80 “Ground” in electronic conditions.

Ground state

[atomic, general, solid-state, thermodynamics] Stable ENERGY configuration for atomic or molecular configuration with respect to the lowest level of energy that does not allow for perturbations. Any energy levels above ground-state will involve energy exchange or the increasing PROBABILITY to liberate free electrons. During interaction of ELECTROMAGNETIC RADIATION with MATTER, the process will be a resonant process for the electrons, in contrast to excitation which is a metastable condition that will eventually revert back to the ground state by single or multiphoton emission. The ground state satisfies the minimum requirements for the Bohr model with respect to the electron orbit filling. Ground state ELEMENTS are also nonradioactive. The ground state is usually attributed with entropy to equal zero: $S_g = 0$, which entails that different constituents all in equilibrium are at zero entropy, each with the lowest possible energy.

Ground state mass

[thermodynamics] The mass (m_g^{free}) of a free constituent at the lowest ENERGY (E_g^{free}), defined by $E_g^{\text{free}} = m_g^{\text{free}} c^2$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light.

Ground state of hydrogen

[atomic, thermodynamics] Hydrogen (H_2) is often referred to as the standard in ENERGY configuration due to it relatively simple structure as the smallest ELEMENT.

Ground wave

[general] Electromagnetic WAVE that travels in the surface layer of the EARTH or close to the surface in the ATMOSPHERE, primarily for AM RADIO wavelengths. These waves follow the curvature of the globe (*also see* SEISMIC WAVE).

Ground-energy state

[thermodynamics] See GROUND STATE, ENERGY.

Ground-energy state, temperature of a

[thermodynamics] Based on the THIRD LAW OF THERMODYNAMICS the temperature of all GROUND states of a system will equal zero.

Ground-energy value, degeneracy of

[thermodynamics] The ENTROPY (S) of any GROUND STATE is defined as $S_g(n, \beta) = k_b \ln(D_g(n, \beta))$, where $D_g(n, \beta)$ is the DEGENERACY of the ground state, for a system with n components and β the parameters describing the conditions of the constituents and $k_b = 1.3806488 \times 10^{-23}$ m²kg/s²K the Boltzmann constant. For a nondegenerate state $D_g(n, \beta) = 1$, while when $D_g(n, \beta) \neq 1$ the system is degenerate.

Ground-state configurations

[atomic, general] Electronic configuration for the GROUND STATE of an ELEMENT. Examples:

ELEMENT	SYMBOL	ATOMIC NUMBER (Z)	ELECTRONIC CONFIGURATION
Hydrogen	H	1	1s
Helium	He	2	1s ²
Lithium	Li	3	1s ² 2s
Beryllium	Be	4	1s ² 2s ²
Boron	Be	5	1s ² 2s ² 2p
Carbon	C	6	1s ² 2s ² 2p ²
Nitrogen	N	7	1s ² 2s ² 2p ³
Oxygen	O	8	1s ² 2s ² 2p ⁴
Fluorine	F	9	1s ² 2s ² 2p ⁵
Neon	Ne	10	1s ² 2s ² 2p ⁶
Sodium	Na	11	1s ² 2s ² 2p ⁶ 3s
Magnesium	Mg	12	1s ² 2s ² 2p ⁶ 3s ²

Group velocity of waves

[atomic, general, nuclear] Propagation speed for the AMPLITUDE of a modulated waveform constructed from a range of wavelengths defined as $v_g = d\omega/dk = v - \lambda(dv_p(\lambda)/d\lambda)$, where $\omega = 2\pi\nu$ is the ANGULAR VELOCITY, for the respective wave FREQUENCY (ν), $k = \lambda/2\pi$ the WAVE number for the respective WAVELENGTH (λ), $v_p = \omega/k$ is the wavelength-dependent PHASE VELOCITY, respectively, across the bandwidth of waves, and v the propagation velocity linked to the wave frequency as $v\lambda = v$; in this case, the propagation speed for the average wavelength of the group of wavelengths traveling through a dispersive medium. When the phase velocity is identical for all waves the group velocity equals the phase velocity. This applies to both mechanical and electromagnetic waves. An example of a compound wave is the electrocardiogram, which can be approximated by a FOURIER SERIES truncated at eight

harmonics, with minimal error. The constituent waves are combined through the superposition principle (see Figure G.81).

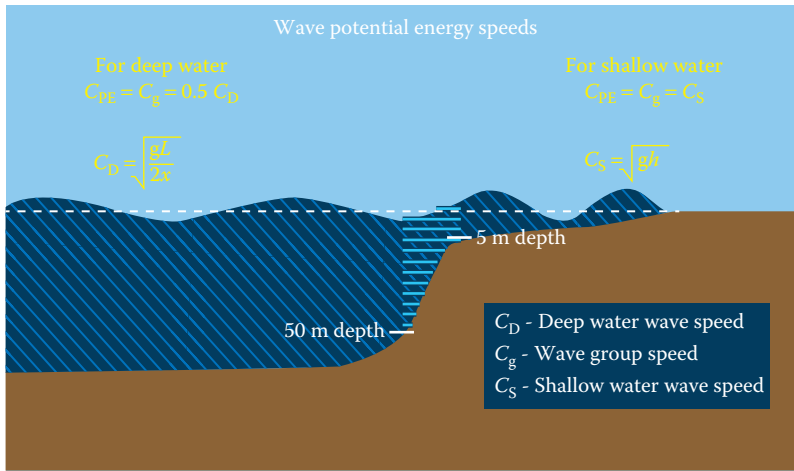


Figure G.81 Group velocity for water waves, the phase velocity of the higher frequencies becomes faster for shallow water, generating the conditions for the “surf” where the higher frequency waves “walk-away” from the base frequency.

Grüneisen coefficient (γ_{Gr})

[thermodynamics] Parameter used to indicate the conversion efficiency of THERMAL ENERGY into mechanical stress expressed as $\gamma_{Gr} = -(V/\Theta_{Debye})(d\Theta_{Debye}/dV)$, where V is the volume of the medium under stress and Θ_{Debye} represents the Debye temperature. This accounts for LATTICE vibrations.

Grüneisen equation

[thermodynamics] Expression for thermal volumetric EXPANSION for a crystalline structure, where generally the volume expansion is the superposition of the linear expansion (α_x) in three dimensions: $\beta_{ex} = (1/V)(\partial V/\partial T)_P = \alpha_{ex,1} + \alpha_{ex,2} + \alpha_{ex,3} = a + bT + cT^2$ as a function of TEMPERATURE (T) with empirical coefficients (a, b, c), which can be converted using the Grüneisen equation to read as $\beta_{ex} = \gamma_{Gr}(c_p/VB_s) = (1/VB_s)(\gamma_{Gr,electron}\alpha_{electron}T + \gamma_{Gr,lattice}\alpha_{lattice}T^3)$, where c_p is the heat capacity at constant PRESSURE (P), V the initial volume, B_s the adiabatic bulk modulus, $\gamma_{Gr,electron}$ and $\gamma_{Gr,lattice}$ are the Grüneisen coefficients for electron and LATTICE contribution, respectively, which accounts for the atomic vibrations as a function of temperature.

Guericke, Otto von (1602–1682)

[astronomy, general] See VON GUERICKE, OTTO (1602–1682).

Guggenheim, Edward Armand (1901–1970)

[thermodynamics] Physicist from Great Britain, seen as the founder of chemical THERMODYNAMICS. The work of Guggenheim provides the definition of PHASE transitions and ENERGY balances involved in the process of PHASE TRANSITION. His work was largely inspired by JOSIAH WILLARD GIBBS (1839–1903) (see [Figure G.82](#)).

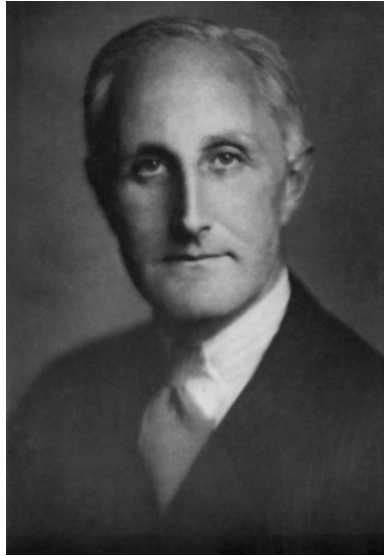


Figure G.82 Edward Armand Guggenheim (1901–1970).

Guided wave

[acoustics, general, optics] WAVE bound by closely confined boundaries, where one boundary may be the bulk medium, but represented by a discontinuity or gradient in the density (mechanical or optical) or in elastic properties. Surface wave are in ACOUSTICS and OPTICS, also described as Rayleigh wave, EVANESCENT WAVE, or surface acoustic wave. Additionally, guided waves are part of FIBER-OPTIC transmission. One specific example is found under LAMB WAVE, describing an atmospheric wave phenomenon. Guided waves also define SEISMIC phenomena (see [Figure G.83](#)).



Figure G.83 Impression of guided wave on the surface of sand. (Courtesy of The Royal Society.)

Guitar

[acoustics, computational] Musical instrument using strings to generate a WAVE pattern that is amplified by a case or is detected by a magnetic ELEMENT that converts the local changes in MAGNETIC FIELD strength into electric signals based on the modulation FREQUENCY SPECTRUM of the strings.

Guldberg, Cato Maximilian (1836–1902)

[computational, thermodynamics] Chemist and mathematician from Norway. Guldberg is known for his definition of the temperature (T) of chemical reaction equilibrium as “the LAW OF MASS ACTION of Guldberg, Waage, van’t Hoff and Horstmann” (see LAW OF MASS ACTION).

Gurney, Ronald Wilfred (1898–1953)

[computational, nuclear] Scientist from Great Britain. Gurney worked on the theoretical description of ionic crystals and discovered the concept of QUANTUM TUNNELING (with respect to ALPHA DECAY). The full quantitative description of the TUNNELING phenomenon was provided by GEORGIY ANTONOVICH GAMOW (1904–1968).

Gutenberg–Richter law

[computational, geophysics] Empirical correlation between the MAGNITUDE (M_{scis}) of earthquakes with respect to the total number of SEISMIC events (N_{scis}) in a specific region as well as over a certain time period, where the magnitudes are in the same range (equal to or greater than M_{scis}), expressed as $N_{\text{scis}} = 10^{a-bM_{\text{scis}}}$, where a and b are constants. The values of b depend on the following conditions: the depth of the WAVE, the locally applied stress, the mechanical mechanism that is the focus of the origin, the heterogeneity of the material, as well as the DISTANCE between the source and any of MACROSCOPIC failure (which creates a discontinuity, which may give rise to REFLECTION and diffraction of the wave). This relationship was defined by BENO GUTENBERG (1889–1960) and CHARLES FRANCIS RICHTER (1900–1985).

Gyro

[general] Generally known as a flywheel or GYROSCOPE, also found under gyrodyne.

Gyromagnetic ratio

[atomic, biomedical] The ratio of the atomic or molecular MAGNETIC DIPOLE moment to the angular momentum of the PARTICLE system. Specific examples are in MRI, more precisely with respect to the LARMOR PRECESSION and for a classical rotation body as well as for a NUCLEUS or isolated electron next to a special relativistic case. For the Larmor precession the gyromagnetic ratio indicates the link between the induced gyroscopic orbital action (with the resulting ELECTROMAGNETIC RADIATION) and the applied MAGNETIC FIELD. For Larmor precession the expression reads $\nu = (\gamma/2\pi)B$, where ν is the PRECESSION frequency, $\gamma_{\text{Larmor}} = -(eg_a/2m_e)$ the gyromagnetic ratio with g_L the electron orbital g -factor, e = the electron charge, m_e the mass of the mass of the precessing electron, and B the applied magnetic field strength. For a classical rotation of a body, the expression is as follows: $\gamma_{\text{classic}} = q/2m$, q the total charge of the rotating body with mass m ; applied as $\mu = \gamma_{\text{classic}}L$, where $\mu = LA$, I the current represented by the moving charge and $A = \pi r^2$ the cross-sectional area of the MOTION with radius r and $L = mvr$ the angular momentum at velocity v . For a nucleus, the gyromagnetic ratio is $\gamma_N = eg_N/2m_p = g_N(\mu_N/\hbar)$, where g_N is the nuclear g -factor, m_p the PROTON mass, $\hbar = h/2\pi$ PLANCK’S CONSTANT $h = 6.626070040(81) \times 10^{-34} \text{ m}^2\text{kg/s (Js)}$, and $\mu_N = e\hbar/2m_p$ the nuclear MAGNETON. The relativistic approach uses the DIRAC EQUATION, providing the gyromagnetic ratio of 2.

Gyroscope

[general] Instrument that is persistent in maintaining its spatial orientation due to an applied angular momentum, first constructed by JEAN BERNARD LÉON FOUCAULT (1819–1868). A gyroscope has a mechanism of high angular velocity rotation while suspended in two or more axis. The main axis of the gyroscope will precess at a fixed angular velocity gives as $\omega_{\text{precess}} = mgr/I\omega$, where m is the gyroscope mass, I the moment of INERTIA for the gyroscope, g the GRAVITATIONAL ACCELERATION, r the DISTANCE from the axis for the center of mass, ω the angular velocity of the spinning mass, and $L = I\omega$ the angular momentum of the rotor inside the gyroscope. A slight error may result from the fact that the vector describing the angular momentum does not exactly line up with the axis of symmetry. This misalignment may cause the gyroscope to wobble up and down or bob. Gyroscopes form a critical component of many guidance systems due to their inherent stability in orientation resilient to displacement, primarily due to the virtually frictionless operation (no external torque applied) (see [Figure G.84](#)).

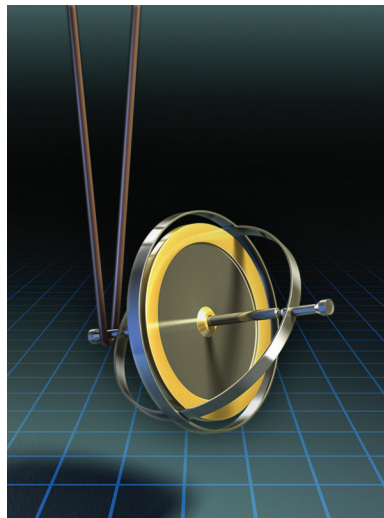


Figure G.84 Stability of a gyroscopic design.

Gyroscopic stability

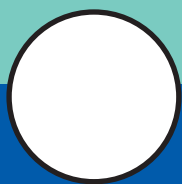
[general] The angular momentum of the GYROSCOPE $L = I\omega$, where I is the moment of INERTIA of the rotating device and ω the angular velocity, makes any change in direction experience a force (i.e., torque) due to the reorientation of the angular momentum. As a result, a gyroscope will tend to remain in the same position when no other forces are acting, which is illustrated when a bicycle is pushed out while the driver jumps off and the bicycle will remain straight and erect until the angular velocity of the wheels is reduced below a critical value and any slight tilt is acted on by GRAVITY.

Gyrostat

[fluid dynamics] Rotating and moving solid within a FLUID environment, generally closed system. Examples can be found in the following: bicycles, flywheels and spherical dampers (SATELLITE; *Note*: has dual SPIN), helicopters (main rotor tied to tail rotor), toy gyroscopes, and unicycles (symmetric wheel) (see [Figure G.85](#)).



Figure G.85 A gyrostat, helicopter.



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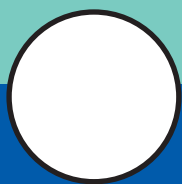
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Preface

The purpose of this *encyclopedia* is to provide a single, concise reference that contains terms and expressions used in the study, practice, and applications of physical sciences. The reader will be able to quickly identify critical information about professional jargon, important people, and events. This encyclopedia gives self-contained definitions with essentials regarding the technical terms and their usages and information about important people in the following areas of physics:

- Acoustics
- Astronomy/astrophysics
- Atomic physics
- Biomedical physics
- Chemical physics
- Computational physics
- Condensed matter
- Dynamics
- Electromagnetism
- Electronics
- Energy
- Engineering
- Fluid dynamics
- General
- Geophysics
- High-energy physics
- Imaging
- Instrumentation
- Materials sciences
- Mechanics
- Meteorology
- Nanotechnology
- Nuclear physics
- Optics
- Quantum physics
- Relativistic physics
- Rheology
- Sensing
- Signal processing
- Solid-state physics
- Theoretical physics
- Thermodynamics
- Ultrafast phenomena

This reference differs from the standard dictionaries in its inclusion of numerous illustrations, including photographs, micrographs, diagrams, graphs, and tables, which support the textual definitions and draw the reader into the explanation to enhance didactic value. Together, these over 2500 entries will educate the reader about the current practice of physics and its applications in biomedicine, materials sciences, chemical engineering, electrical engineering, mechanical engineering, geology, astronomy, meteorology, and energy.

It is envisioned that novices and trainees, in addition to seasoned professionals, will find this resource useful, both for sustained reading and for taking a dip into the topics periodically. The contents are also designed to help the professionals who are new to a work environment and recently enrolled students who need to become more familiar with terminology and nuances relevant to certain research and applications. Moreover, it will assist in understanding the primary literature as well as technical reports and proposals. Finally, any student from the high school to graduate levels should be able to benefit from the broad and applied emphasis of this concise encyclopedia, which may support undergraduate courses in applied sciences for nonscience majors.

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He cofounded several companies in biomedical engineering and worked for several established metrology and medical device companies. In addition, Dr. Splinter worked in clinical settings, prototyping, and validating devices using the full practical and theoretical knowledge of physics, engineering, electrical engineering, chemistry, and biology. He is an associate professor (Adj.) in the Department of Physics at the University of North Carolina at Charlotte.



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H

[atomic, chemical] HYDROGEN ATOM [${}^1_1\text{H}$], most elementary ELEMENT known. The hydrogen excitation spectra are described by the BALMER SERIES, discovered by JOHANN JAKOB BALMER (1825–1898) in 1885 with the FREQUENCY (ν) spectrum defined as $\nu = cR[(1/2^2) + (1/n^2)]$, where $R = 10,967,758\text{ m}^{-1}$ is the RYDBERG CONSTANT, $c = 299,792,458\text{ m/s}$ is the speed of light, and $n = 3, 4, 5, \dots$ is an integer depicting the excitation levels. The Balmer series emission lines (i.e., ATOMIC LINE SPECTRA) are all in the visible spectrum.

H₂ problem

[atomic, computational, condensed matter, energy, mechanics, solid-state] The SCATTERING of electrons of hydrogen forms an interesting computational problem with respect to the theoretical observations. The electron scattering process is apparently a function of the electron density based on the acting strong and weak forces on atomic level. The electron velocity (i.e., momentum) distribution is non-Gaussian, providing an INELASTIC SCATTERING model. The ENERGY configuration of the hydrogen MOLECULE creates an interesting format due to the fact that the protons can have identical SPIN and this leads to DEGENERACY. While the electrons are energetically forced to be antiparallel (PAULI EXCLUSION PRINCIPLE), this does not apply to the protons since they are not in the same ATOM, whereas the electrons are shared between the atoms. The PROTON spins form both a SINGLET and a TRIPLET.

Haas, Arthur Erich (1884–1941)

[atomic, nuclear, quantum] A physicist and scientist from Austria. Arthur Haas defined that electrons orbit around, then still undefined, the NUCLEUS of the atomic structure in uniform circular orbit with “fixed” radius in 1910, predating the atomic model developed by NIELS HENRIK DAVID BOHR (1885–1962) by three years. This was a substantiated contribution to the QUANTUM principles (see [Figure H.1](#)).



Figure H.1 Arthur Erich Haas (1884–1941). (Courtesy of Universitätsarchiv Leipzig, Leipzig, Germany.)

Haas, Georg (1886–1971)

[biomedical] A physician from Germany that is known to perform the first human KIDNEY dialysis in 1926, following in the footsteps of THOMAS GRAHAM (1805–1869), ADOLF EUGEN FICK (1829–1901) [also known for FICK'S LAW], and JOHN JACOB ABEL (1857–1938). Even though all of his patients eventually died either from the procedure or from the consequences of the disease, the process was later perfected by WILLEM JOHAN KOLFF (1911–2009) and is still in use (see [Figure H.2](#)).



Figure H.2 Georg Haas (1886–1971).

Hadron

[atomic, general, high-energy, nuclear] The generic name of a PARTICLE class with a strong inter-particle attraction. Hadrons are, for instance, protons (subclass: BARYON), neutrons (subclass: baryon), as well as the δ , K, and D mesons, and their respective antiparticles. The known constituents of ordinary nuclei, PROTON and NEUTRON, are members of a hadron subclass called BARYONS. Other baryons are “strange” ($\bar{s}$) and “charmed” ($\bar{c}$), for example, 0 s and 0 c. Baryons obey FERMI–DIRAC STATISTICS, have half-integral SPIN, and are also known as FERMIONS. Another subclass of hadrons: MESONS obey BOSE–EINSTEIN STATISTICS, have zero or integral spin, and are known as BOSONS. The ELECTRIC CHARGES of baryons and mesons have three options: either zero or a charge equivalent to the electron in either positive or negative value.

Hagen, Gotthilf Heinrich Ludwig (1797–1884)

[engineering, fluid dynamics] A hydraulic engineer and physicist from Germany (Prussian Empire). Gotthilf Hagen provided a significant theoretical description with respect to hydraulic displacement

and FLOW. Specifically, the HAGEN–POISEUILLE LAW summarizes the combined efforts by Gotthilf Hagen and JEAN LÉONARD MARIE POISEUILLE (1799–1869) (see [Figure H.3](#)).



Figure H.3 Gotthilf Heinrich Ludwig Hagen (1797–1884).

Hagen–Poiseuille law

[biomedical, fluid dynamics, rheology] A viscous flow rate for a NEWTONIAN FLUID flowing through a tube is described by the correlation between the rate of flow (Q) of a fluid (Q/t , over time t) with respect to the WALL stress ($\sigma_r = Pr/2\ell = F_{xy}/A_{xy} = \eta[d(dx/dy)/dt]$, for the force: F_{xy} over an area A_{xy}) and the radius of the tube (r) and the length of the flow (ℓ), all in relation to the VISCOSITY (η) when a PRESSURE (P) is applied, expressed as $Q/t = \pi Pr^4/8\eta\ell$. This FLOW dynamic description was defined independently by both JEAN LÉONARD MARIE POISEUILLE (1799–1869) in 1838 and GOTTHILF HEINRICH LUDWIG HAGEN (1797–1884) in 1839.

Hahn, Otto (1879–1968)

[general, nuclear] A German chemist and scientist who, working with LISE MEITNER (1878–1968), a Jew under Hitler's directive, and FRIEDRICH WILHELM "FRITZ" STRASSMANN (Straßmann, 1902–1980), verified the predictions of ENRICO FERMI (1901–1954) followed by IDA NODDACK (1896–1978) regarding the splitting of uranium by bombardment with thermal NEUTRON in 1938. Hahn described the principle of FISSION of heavy nuclei and received the Nobel Prize in Chemistry in 1944 on this work. The Hahn–Meitner–Strassmann experiment revealed the uranium was split into isotopes of the ELEMENT barium $^{138}_{56}\text{Ba}$ and $^{95}_{36}\text{Kr}$ (krypton ISOTOPE) and three neutrons with the difference in mass expressed as energy 216 MeV for splitting one MOLECULE, the equivalent of the ENERGY released resulting from the combustion of approximately 1 million molecules of gasoline (approximately 1×10^{16} l of GAS at standard pressure $[P]$ and standard temperature $[T]$; from $PV = nRT$, where n is the number of moles [1 mole = 6.022×10^{23} molecules, i.e., Avogadro's number $N_A = 6.022 \times 10^{23}$], and $R = 8.3145 \text{ J/molK}$ the universal gas constant), as derived

and concluded by LISE MEITNER (1878–1968) and her nephew Otto Robert Frisch (1904–1979) in late 1938 while working at the Bohr Institute in Copenhagen (see [Figure H.4](#)).



Figure H.4 Otto Hahn (1879–1968) in 1944.

Hale, George Ellery (1868–1938)

[astronomy/astrophysics, optics] An astronomer and physicist from the United States. In 1908, Hale discovered the MAGNETIC effects of sunspots associated with their inherent vorticity under examination with the spectrohelioscope of his own design (see [Figure H.5](#)).



Figure H.5 George Ellery Hale (1868–1938). (Courtesy of *The World's Work: A History of Our Time*, Vol. XXV, Doubleday, Page & Company, Garden City, NY, 1913.)

Hale's law

[astronomy/astrophysics] A description of the symmetry in MAGNETIC polarity in correlation with sunspot cycles from northern to southern hemisphere.

Hale–Bopp comet

[astronomy/astrophysics] A COMET discovered in 1995 by Alan Hale (1958–) and amateur astronomer Thomas Bopp (1949–), remaining visible for more than 18 months. The trajectory of the Hale–Bopp comet has a period of approximately 4200 years (see [Figure H.6](#)).



Figure H.6 Picture of Hale–Bopp comet with the separate gas trail and the ion tail visible.

Half thickness ($d_{1/2}$)

[atomic, biomedical, computational, general, nuclear] The thickness of absorbing material necessary to reduce the intensity of RADIATION to one-half (50%) of its incident value.

Half-cell

[biomedical, chemical, electromagnetism, energy, general, solid-state] Two cells in contact but separated by a semipermeable BARRIER allowing for a slow and controlled chemical reaction. One CELL has an ELECTROLYTE with cations and the other cell has an electrolyte that produces anions. The connection between the two cells induces a FLOW of electrons that reduces the cations and oxidizes the anions. The connection between the two half-cells can be made by means of a wire where the ELECTRODE in the CATION solute is the CATHODE and the electrode in the electrolyte with anions is the ANODE. In biology, half-cells generate electric potentials that can be measured externally while performing electric communications and inducing actions in the biology, such as the formation of the NERNST POTENTIAL, and inducing muscular contraction and neural transmission of sensations and delivery of triggers to instigate actions. The half-cell potential in batteries provides the ENERGY for operation of electrical devices, whereas in biology this is measured by means of electrodes on the SKIN or needle electrode based on the respective mechanism of action resulting

from ELECTROMYOGRAM for muscle action, ELECTROENCEPHALOGRAM for brain ACTIVITY, and ELECTRO-CARDIOGRAM for cardiac contraction to name a few (see Figure H.7).

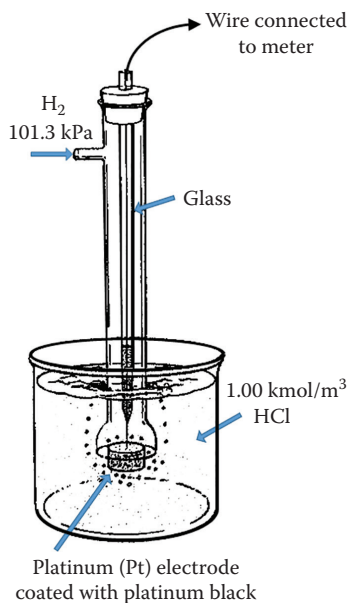


Figure H.7 Electrochemical design of the half-cell concept.

Half-life ($\tau_{1/2}$)

[atomic, biomedical, computational, general, nuclear] The time required for one-half of the atoms of the substance originally present to DECAY by RADIOACTIVITY $\tau_{1/2} = 1/\lambda_{1/2}$, where the decay constant $\lambda_{1/2} = (\Delta N/\Delta t)/N$ represents the change in the number of isotopes of reactive atoms N over time with respect to the original quantity by half, which is a fixed number for any specific element or ISOTOPE. For radioactive isotopes, the half-life ranges from 10^{-22} s to 10^{21} year. ERNEST RUTHERFORD (1871–1937) introduced this term representing the period in which the decay rate R drops to $(1/2)R_0$ (see Figure H.8).

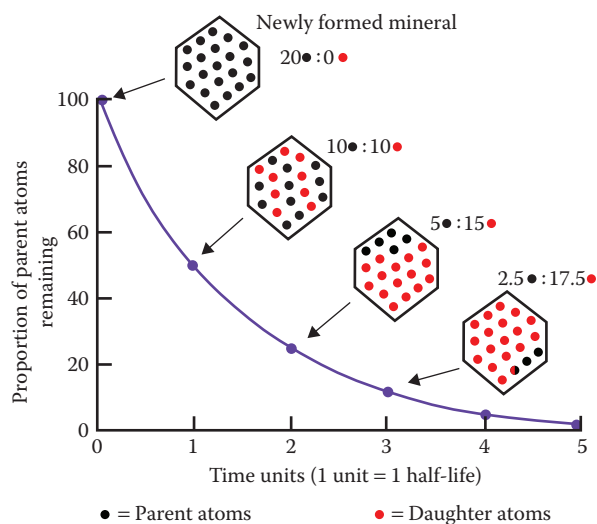


Figure H.8 How the half-life represents the time to reduce the quantity of seed atoms by half.

Halley, Edmund (1656–1742)

[astronomy/astrophysics, general] An astronomer, mathematician, and physicist from the United Kingdom/Great Britain. Halley used prior data and his own observations to describe a recurring COMET (in 1682), now named HALLEY'S COMET. Halley defined the trajectory and axes of the orbit (see Figure H.9).

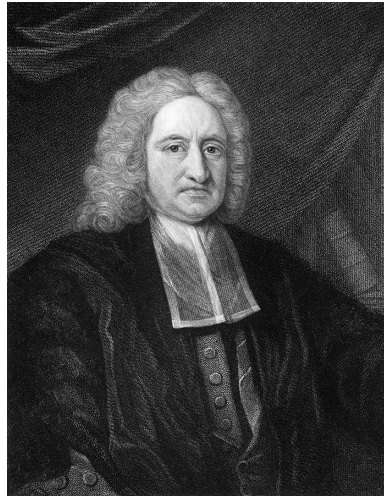


Figure H.9 Edmond Halley engraved by W. T. Fry.

Halley's comet

[astronomy/astrophysics, general] A COMET that is described in various books and transcripts dating back to the early Greek astronomy researchers (minimally 240 BC), but is named after the scientific contributions by EDMUND HALLEY (1656–1742) from his 1682 observation, also described by JOHANNES KEPLER (1571–1630) in 1607. The comet has a trajectory that makes it pass EARTH every 75–76 years (depending on the earth's position and the accuracy of early recordings) with two observations, before reaching the Sun and after returning from its orbit around the Sun. Initially considered as two independent comets, as described by SIR ISAAC NEWTON (1642–1727), but corrected by Edmund Halley. The Halley's comet has the shortest period of all known comets that are visible from the Earth, specifically with the rudimentary telescopes available over the past several centuries.

Hamilton, William Rowan, Sir (1805–1865)

[computational, general] A mathematician and physicist who formalized the concepts introduced by PIERRE DE FERMAT (1601–1665) (with respect to light in his case) that actions take the path of least RESISTANCE. In Fermat's case, this led to SNELL'S LAW of refraction, whereas PIERRE LOUIS MOREAU DE MAUPERTUIS (1698–1759) in 1747 described the same principle for any action or FLOW of ENERGY, much later formalized by Hamilton as $\sum \vec{p} \Delta q \downarrow$ minimum, where $\vec{p} = m\vec{v}$ is the momentum (MASS (m) times VELOCITY ($\vec{v}$), but can also be angular momentum $\vec{L} = I\vec{\omega} = r_{\perp}mv$, $I = \sum mr^2$ the MOMENT OF INERTIA of a body with mass m in motion with $r_{\perp}$ the DISTANCE in perpendicular direction from the MOTION to the center of symmetry of the motion and ω the ANGULAR VELOCITY) and q is a spatial indicator (for instance, $q_1 = x$), also referred to as conjugate space variable, which for angular momentum translate into ANGLE in space instead of location in CARTESIAN COORDINATES. The description of Hamilton involves the introduction of spatial surfaces on which the action of the motion of the system is constant. The surfaces of constant action, as they are referenced, traverse space in the same fashion as how Fermat described the propagation of the PHASE of electromagnetic wave fronts in OPTICS.

In energetic format, the Hamilton equation uses the total energy ($KE + U = E$, the sum of kinetic ($KE = (1/2)mv^2 = p^2/2m$) and potential (U) energy) as $(1/2m)p^2 + U = E$. This concept was adapted by ERWIN SCHRÖDINGER (1887–1961) into a differential equation, the WAVE EQUATION. The EQUATIONS OF MOTION in Hamiltonian space are now $\dot{p}_j = -(\partial H/\partial q_j)$ and $\dot{q}_j = +(\partial H/\partial p_j)$, with $H(p, q) = \sqrt{(m^2 + p^2)}$ the Hamiltonian function of energy for a PARTICLE (see Figure H.10).



Figure H.10 William Rowan Hamilton (1805–1865).

Hamiltonian energy

[computational, energy, mechanics] $H(p, q) = \sqrt{(m^2 + p^2)}$ is the Hamiltonian function of ENERGY for a PARTICLE with mass m and momentum $p = mv$, where v is the velocity of the moving system.

Hamiltonian mechanics

[computational, energy, fluid dynamics, mechanics] In kinetics, there is acceleration, constant speed, ENERGY, and momentum with respect to either linear, curved (~Coriolis), or rotational displacement. In Hamiltonian mechanics, the energy is depicted through PHASE and spatial orientation and location. The HAMILTONIAN ENERGY is $H(q, p)$.

Hamiltonian operator

[atomic] Also Hamiltonian (H), the ENERGY operator belonging to the Hamilton energy: $H = KE + U = (p^2/2m) + U$, the sum of kinetic ($KE = (1/2)mv^2 = p^2/2m$) and potential (U) energy, expressed as $H^{\text{op}} = -(\hbar^2/2m)\nabla^2 + U = -(\hbar^2/2m)[(\partial^2/\partial x^2) + (\partial^2/\partial y^2) + (\partial^2/\partial z^2)] + U$, where $\hbar = h/2\pi$, $h = 6.626076$ Js Planck's constant, for a PARTICLE with mass m and momentum $p = mv$, where v is the velocity of the moving system. The Hamiltonian operator was introduced by SIR WILLIAM ROWAN HAMILTON (1805–1865) over the period 1823–1828. The Hamiltonian can be a matrix with a considerably large number of matrix ELEMENTS $H^{\text{op}}_{\vec{k}}(\vec{k}) = \int \Phi_i^*(\vec{k}, \vec{r}) H \Phi_i(\vec{k}, \vec{r}) d^3r$, where $\Phi_i^*(\vec{k}, \vec{r})$ is the complex conjugate of the general number of base sets $\Phi_i(\vec{k}, \vec{r})$ with respect to a previously specified set of functions $\Phi_i(\vec{k}, \vec{r} + \vec{R}_i) = \exp(i\vec{k} \cdot \vec{R}_i) \Phi_i(\vec{k}, \vec{r})$, with LATTICE vector $\vec{R}_i = n_{i1}a_1 + n_{i2}a_2 + n_{i3}a_3$, using three primitive lattice vectors a_j and n_{ij} integers; r is the location in three-dimensional space and $\vec{k}$ is the WAVE vector that can be equated to a QUANTUM number defining the electron states.

Hankel function

[computational] A function series, designed in an approximation of complex mathematical functions. Hankel functions are some of the solutions that apply to the Helmholtz equation, in the form of cylinder harmonics. One kind of Hankel functions is the BESSEL FUNCTIONS of the third kind (also known as Weber functions). The Hankel functions of the first kind are combinations of Bessel functions of the first ($J_n(z)$) and second ($Y_n(z)$) kind $H_n^{(1)}(z) \equiv J_n(z) + iY_n(z)$, also known as spherical Hankel functions. The Hankel functions of the first kind can be represented by contour integration over the upper half-plane $H_n^{(1)}(z) = (1/i\pi) \int_0^\infty \int_{\text{upper half plane}} e^{(z/2)(1-(1/t))} / t^{n+1} dt$. The second class of Hankel functions is defined by a specific contour (C_e , Hankel contour) integral, defined by $H_e(z) = \int_{C_e} (-w)^{z-1} e^{-w} / (1 - e^{-w}) dw$.

Harmonic motion

[acoustics, fluid dynamics, general, mechanics] Sinusoidal oscillation, rhythmic vibration with fixed frequency. Generally, in harmonic motion the restoring force is proportional to the displacement, as found for HOOKE'S LAW with respect to a spring. When any form of DAMPING is applied, FRICTION or FLOW, the harmonic motion becomes a damped HARMONIC OSCILLATION (see DAMPED OSCILLATION and OSCILLATION). A simple harmonic oscillation can be represented as the projection of a circular motion. The generalized description of the periodic displacement (y) with AMPLITUDE A_0 and ANGULAR FREQUENCY ω for the harmonic motion is a sinusoidal function, which includes a phase offset (φ) $y(t) = A_{1,0} \sin(\omega t) + A_{2,0} \cos(\omega t) = A_0 \cos(\omega t - \varphi) = A_0 \cos(2\pi\nu t - \varphi)$ as a function of time (t), with frequency ν . A forced harmonic motion can result in RESONANCE under the appropriate boundary conditions (see Figure H.11).

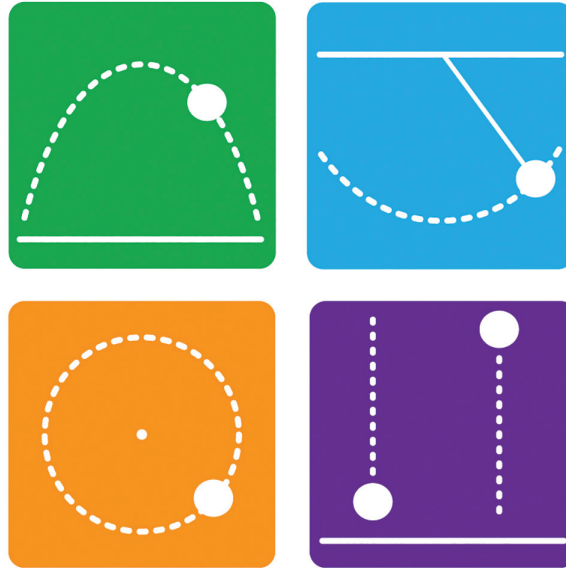


Figure H.11 Examples of harmonic motion.

Harmonic oscillation

[acoustics, atomic, fluid dynamics, general, mechanics, thermodynamics] Periodic **OSCILLATION**, **HARMONIC MOTION**. Sound is an acoustic harmonic pressure fluctuation with a specific frequency. Harmonic oscillations generally are the spectrum starting out with the base **FREQUENCY** (ν_0 , also referred to as **FUNDAMENTAL** frequency ν_1) and associated higher harmonics, at respective frequency $\nu_n = n\nu_0$, $n = 1, 2, \dots$. In atomic **PHYSICS**, the electron orbit in the Bohr model performs a harmonic oscillation that is a perfect match to the orbit, a **QUANTUM** harmonic oscillator (classical physics) with **ENERGY** $E_n = [n + (1/2)]h\nu$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is the Planck's constant (*also see* **OSCILLATION**, **QUANTUM OSCILLATOR**, and **NATURAL FREQUENCY**) (see [Figure H.12](#)).

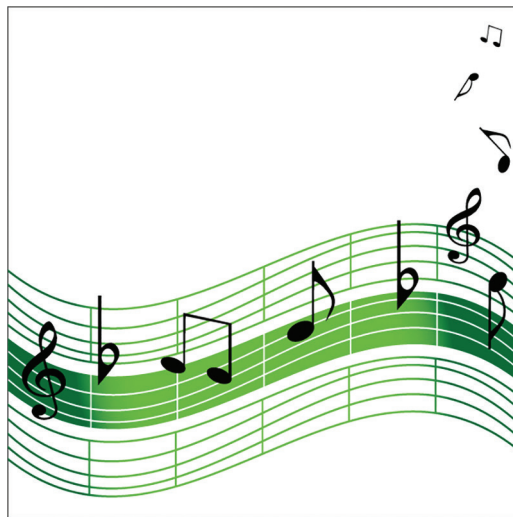


Figure H.12 Musical notes are a prime example of harmonic oscillation, each with a specific base frequency. The harmonic motion for sound is longitudinal pressure waves in fluids or solids.

H-bomb

[atomic, nuclear] A hydrogen fusion bomb ${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^2_1\text{H} + e^+ + \nu_e$, emitting a **DEUTERON** (${}^2_1\text{H}$) and a **NEUTRINO** (ν_e) as well as **ENERGY**. This principle also applies to the operations of stars and our Sun. The deuteron (“deuterium”, also presented as ${}^2_1\text{D}$) immediately fuses with another hydrogen nucleus, emitting gamma radiation (γ) and energy ${}^1_1\text{H} + {}^2_1\text{H} \rightarrow {}^3_2\text{He} + \gamma + \text{energy}$. Alternatively, ${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^3_2\text{He} + n + 3.3 \text{ MeV}$, releasing tritium (${}^3_1\text{T}$ and a **PROTON**) and a **NEUTRON** (n). The final stage in the **FUSION** process is the formation of helium ${}^3_2\text{H} + {}^3_2\text{H} \rightarrow {}^4_2\text{He} + 2{}^1_1\text{H} + \text{energy}$, alternatively

${}^2_1\text{H} + {}^3_2\text{H} \rightarrow {}^4_2\text{He} + \text{proton} + 18.3\text{MeV}$, or ${}^2_1\text{H} + {}^3_2\text{T} \rightarrow {}^4_2\text{He} + \text{neutron} + 17.6\text{MeV}$. H-bomb is also known as the ATOMIC BOMB (see FUSION) (see [Figure H.13](#)).



Figure H.13 Recovered hydrogen bomb, lost during a midair collision of B-52 bomber plane and a refueling plane in their path over Palomares, Spain, in 1966.

He4, 4Helium (${}^4\text{He}$)

[astronomy/astrophysics, biomedical, chemical, general] The ELEMENT helium.

Head loss

[fluid dynamics] Loss in the equivalence of ENERGY expressed as the loss in height of a column of LIQUID (representative of the local Bernoulli pressure), expressed as $h_s = (P_1 - P_2)/\rho g$, where the pressure prior to the segment under consideration is P_1 and after the segment P_2 , with g the GRAVITATIONAL ACCELERATION and ρ the FLUID density (see [Figure H.14](#)).

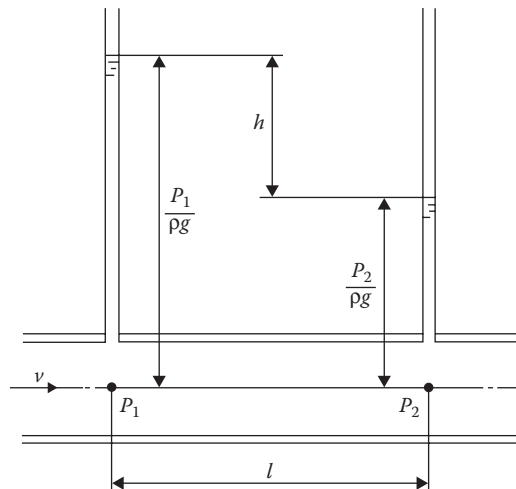


Figure H.14 Head loss in pipe flow with pressure drop over distance.

Head loss, Borda–Carnot

[fluid dynamics] Head loss due to an EXPANSION in fluid flow, expressed as the “Borda–Carnot head loss” $h_s = (v_1 - v_2)/g$, where the average flow velocity prior to the expansion is v_1 and after the expansion v_2 , with g the GRAVITATIONAL ACCELERATION (see [Figure H.15](#)).

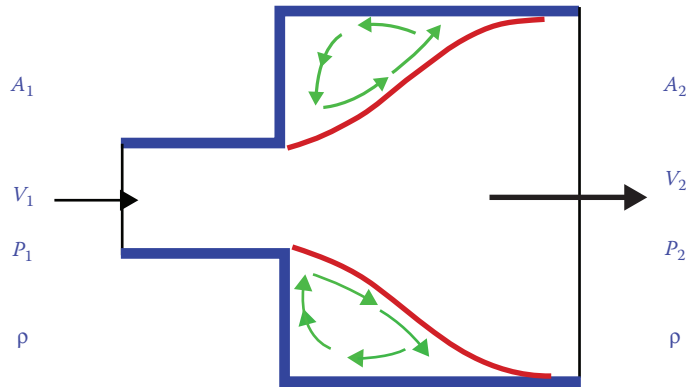


Figure H.15 Illustration of the concept of Borda–Carnot head loss.

Head-on collisions

[general, mechanics] Two objects with respective opposite velocity vectors, which are perfectly aligned, reach a position where they make physical contact (see [Figure H.16](#)).

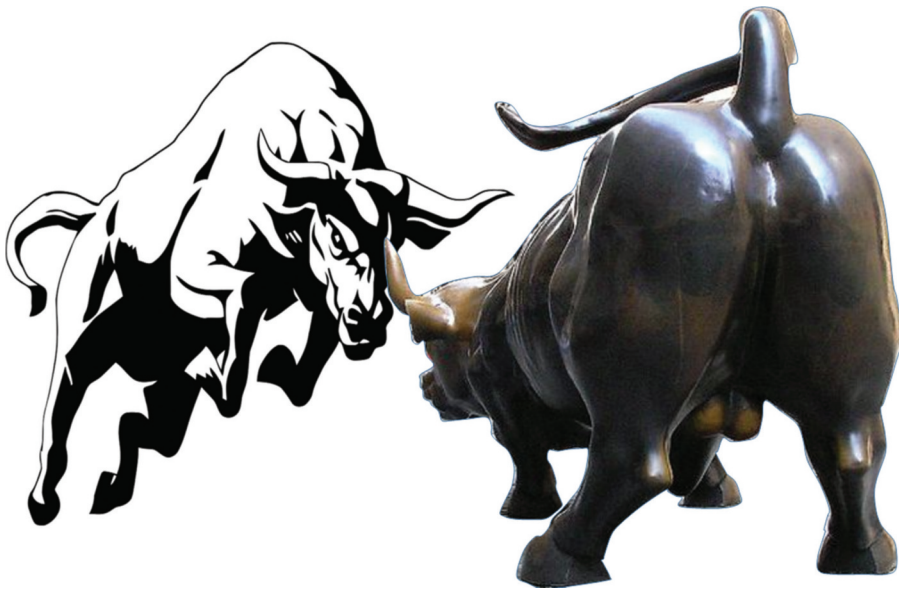


Figure H.16 Head-on collision example.

Health physics

[atomic, biomedical, general, imaging, solid-state] A designation of professional field in MEDICINE, often specifically geared to RADIATION controls and imaging accuracy. The major responsibility of the health physicist is often in NUCLEAR MEDICINE. The health physicist role varies from country to country, based on traditional role and academic involvement. In most cases, the work effort involves a multitude of PHYSICS, ENGINEERING, and biology as well as chemistry knowledge, related to quality control of diagnostic and safety issues next to basic science and device development (see Figure H.17).

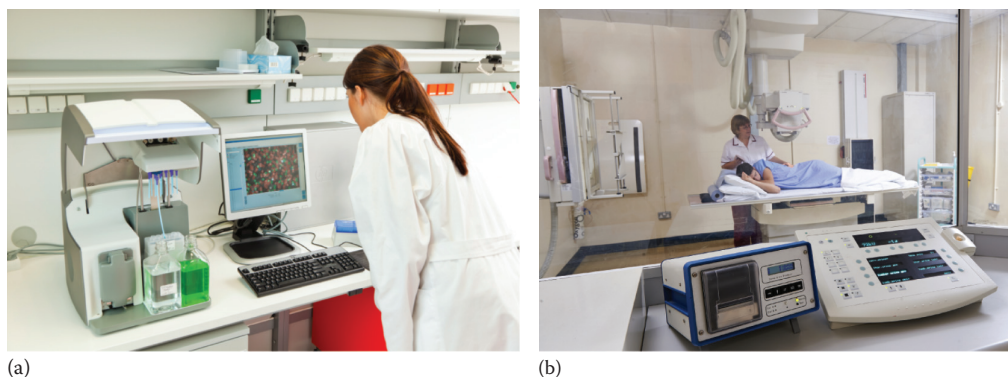


Figure H.17 Example of a health physics aspect involving the diagnostic and therapeutic modalities for clinical care: in vivo examination of equipment (a) and application (b).

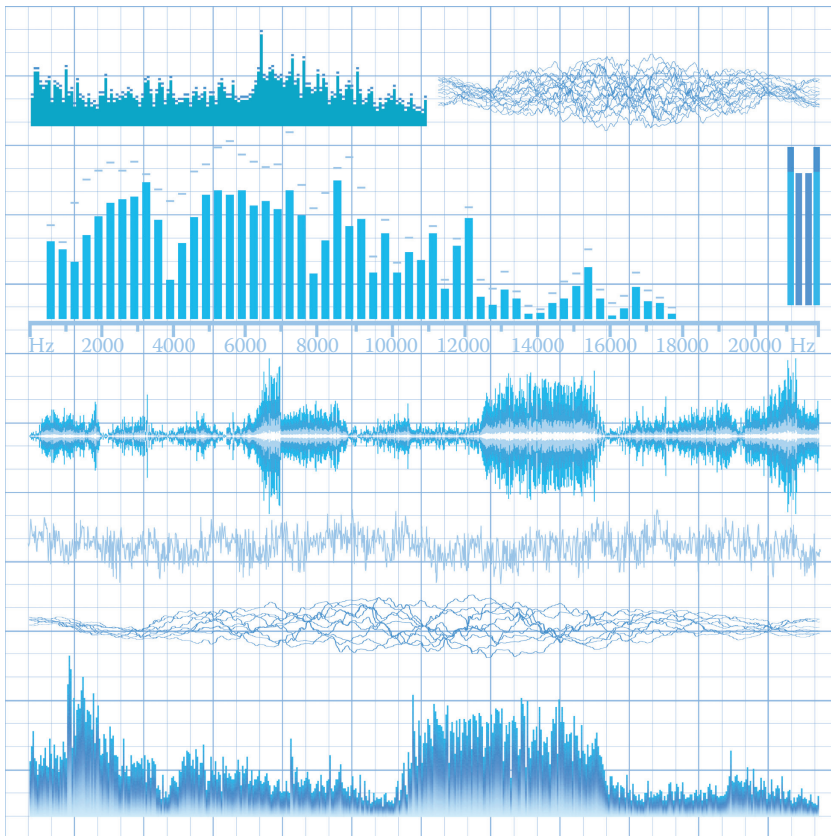
Hearing

[acoustics, general] The conversion of mechanical waves in electronic pulse train by a biological device such as an EAR. The human ear has three anatomical components: OUTER EAR, MIDDLE EAR, and INNER EAR. In the outer ear, the pressure waves are guided into the middle ear by means of the horn-shaped exterior shell leading into the auditory meatus (ear canal). At the tympanic membrane of the middle ear, the pressure waves are converted into mechanical waves on a solid. The oval window connects to the liquid-filled inner ear, where the mechanical waves are passing through the COCHLEA. The human ear due to its cochlear construction performs a mechanical FOURIER TRANSFORM of the SOUND impacting on the oval window of the eardrum, splitting the pressure wavelengths out from short near the entrance (high frequencies are converted into electronic pulses, i.e., ACTION POTENTIAL spikes, close to the oval window) to long toward the end of the coil, which is actually near the point of entry since the design of the cochlea allows the WAVE propagation to double over at the tip of the coil. Each location on the inner design of the cochlea hence responds to a narrow wave band and the resulting electronic pulse train indicating the AMPLITUDE of the locally detected sound wave to be encoded for neural processing in the brain by binary processing (i.e., digitized). A variety of conversions take place in the ear, ranging from conversion of pressure changes in mechanical momentum of MOTION at the tympanic membrane $P(t) = mv(t)/tA = F/A$, where $P(t)$ is the time modulated pressure (sound), m the mass of the tympanic membrane, A the area of the tympanic membrane, $v(t)$ the time varying velocity of motion of the MEMBRANE, and F the force. In this situation with kinetic transfer, there will be a need for impedance matching to ensure transfer of ENERGY with maximum efficiency and without frequency filtering. Generally, the human ear can detect sound waves with a frequency range of roughly 20 Hz to 20 kHz (approximately 8 octaves, as a rule diminishing with AGE), which changes with age due to degradation of the elastic modulus of a variety of the components involved: tympanic membrane, muscular suspension of the malleus, incus, and stapes as well as the ORGAN OF CORTI. Additionally, nerve degeneration also affects the hearing. Animals have a different spectral range depending on the specific functional use. For instance, certain bats are reported to have hearing extending into the 400 kHz range with lower limit of approximately 20 Hz (generally, the upper limit is 120 kHz for

the average BAT), dogs are sensitive from 60 to 40,000 Hz and for cats it is generally higher, whereas bottlenose dolphins are sensitive in the range 200 Hz to 150 kHz and certain whales have a 12-octave range of detection starting as low as 16 Hz (*see* EAR) (*see* [Figure H.18](#)).



(a)

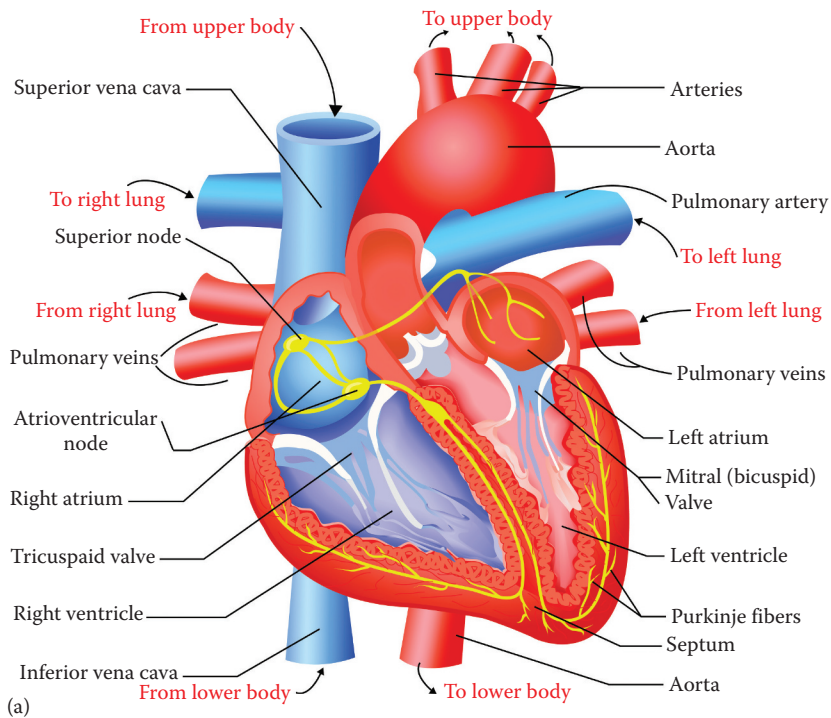


(b)

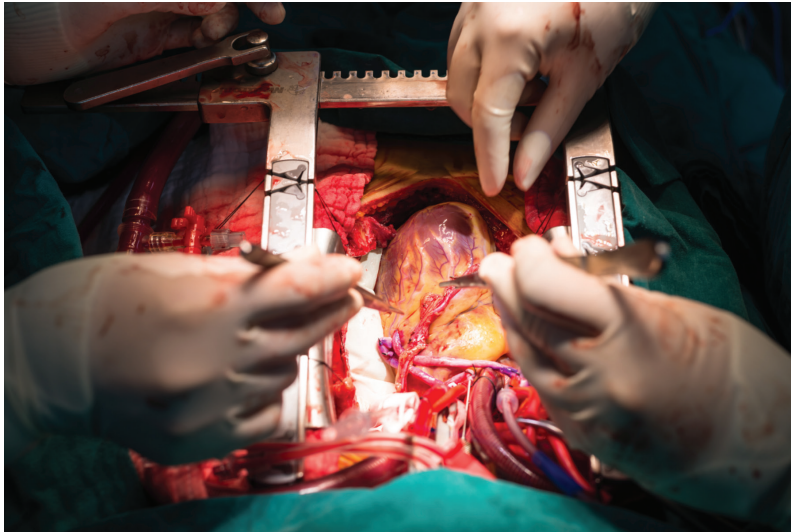
Figure H.18 Spectral profile span for a frequency spectrum (b) of an equalizer recording display (a).

Heart

[biomedical, chemical, fluid dynamics, mechanics] A hollow MUSCLE designed to pump BLOOD through a biological system when contraction takes place. The HEART acts with two pumps in series, one to circulate blood through the body and the other through the lungs. The arteries are providing the outflow tubes for the heart connected to the ventricles. The arteries in general carry oxygen-rich blood, except for the pulmonary artery leaving from the right ventricle to the lungs. The FLOW system is mediated by mechanical valves that open under applied pressure and close when specific components of the heart muscle are relaxing. The left atrium is separated from the left ventricle by means of the mitral VALVE, leading into the AORTA closed off by the aortic valve. The right atrium is prevented from receiving backflow from the right ventricle as a result of the tricuspid valve, and subsequent at the outflow into the pulmonary artery, the system has one-way flow only by means of the pulmonary valve. The atria (left and right atrium) collect blood on return from the body and lungs, respectively, and provide a windkessel SOLUTION in temporary storage for before transferring the content to the respective ventricles. The COMPLIANCE (C_{compl}) of the vascular system is defined by the ability to change the VOLUME (V) under influence of a change in pressure (P): $C_{\text{compl}} = \Delta V / \Delta P$. The TENSION (T) in the cardiac muscle wall of the heart is defined through the LAPLACE LAW, based on the PRESSURE (P) in the ventricle (primary muscle segment of the heart) and the radius (R) of the ventricular volume (assumed as a cylinder), divided by the WALL thickness (b): $T = (P \times R) / b$. The vascular compliance mediates the forced outflow from the ventricles into a resistive flow system of arteries, arterioles, and capillaries, flowing out into the venules and finally the veins, leading back to the respective left and right atrium. The myocardial muscle is a special muscle, unlike any other muscle in the body, human or other animal. The average power output of the human heart per contraction beat (averaged over AGE and gender) is 1.33 W (Note: 1 W = 1 J/s = 1 Nm/s, compare to a refrigerator on average 615 Watt and the SOLAR POWER incident on a square meter 1380 Watt—the work per unit time), which can be calculated from the pressure produced by the heart multiplied by the flow rate (Φ), using $P = 1.33 \text{ N/m}^2$ and $\Phi = 1.05 \times 10^{-4} \text{ m}^3/\text{s}$: $P_{\text{power}} = P \times \Phi$. The heart pumps based on an autonomic system that depolarized the atrium in order to stimulate for contraction by means of the sinoatrial node (SA node), followed by the DEPOLARIZATION of the atrioventricular node (AV node) on the ventricle for ventricular contraction. Both the SA node and AV node can be modified in their depolarization rate based on several chemical, neurochemical, and mechanical factors, hence increasing the heart rate under exercise. Since all the components of the cardiac flow system have very different parameters: number of vessel, diameter, compliance, and flow RESISTANCE, the system can be treated as a cascade of systems that are continuous at the connecting points, which is generally represented by means of Bond graphs (see Figure H.19).



(a)



(b)

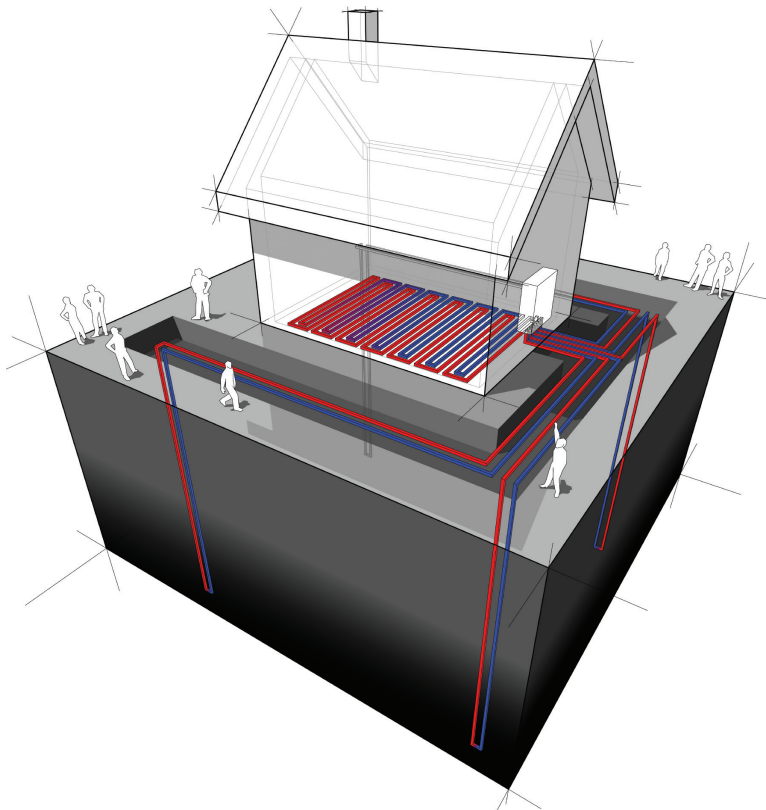
Figure H.19 (a) Anatomy of the heart and (b) open chest surgery, exposing the heart.

Heat (Q)

[energy, general, nuclear, thermodynamics] An indication of the thermal process of transfer of **ENERGY**. This is not equivalent to the definition of temperature, which is the indication of the ability to transfer heat; not equivalent to **THERMAL ENERGY**: the energy of random **MOTION** in kinetic energy as well as stored in potential energy on atomic and molecular scale. Heat and work both represent the specific phenomenological description of energy in motion. One specific application of heat is in **CALORIMETRY**, which is used to indicate the interchange of energy (see [Figure H.20](#)).



(a)



(b)

Figure H.20 (a) Illustration of a geothermal heating arrangement, explaining (b) the heat exchange with a volume at constant temperature (subterranean Earth).

Heat, mechanical equivalent

[thermodynamics] In 1842, the German physician JULIUS ROBERT VON MAYER (1814–1878) hypothesized that the MECHANICS of expanding gasses could be coupled to the transfer of ENERGY in the form of heat and introduced the mechanical equivalence of heat (Q), or rather the relationship between work (W) and heat as $W = Q$; this was corroborated by the paper of JAMES PRESCOTT JOULE (1818–1889) in 1843.

Heat capacity (c)

[thermodynamics] The amount of HEAT (Q) necessary to raise the temperature of a substance by 1 K, in a specific PHASE, indicated by a subscript for the specific medium when used in heat exchange and establishing THERMAL EQUILIBRIUM as described by the ZEROth LAW OF THERMODYNAMICS or in any heat exchange between two or more bodies with respective mass (m_i) and of unlike temperature resulting in a respective temperature change (ΔT_i) for each based on the heat exchange $-Q_3 = Q_1 + Q_2 = -m_3 c_3 \Delta T_3 = m_1 c_1 \Delta T_1 + m_2 c_2 \Delta T_2$. Unit: J/kgK. In popular scientific terms, this relates to the capacity of a body to maintain its temperature or rather exchange the heat resulting from the temperature gradient with respect to a body in contact, for instance, comparing a block of cork to a GLASS ball of equal mass and elevated temperature (*also see CALORIE*).

Heat of dissociation

[thermodynamics] *See* HEAT OF FUSION.

Heat of fusion (L_f)

[general, thermodynamics] The quantity of heat per unit mass required to liquefy a solid object while at its melting temperature $Q = \pm mL_f$ (*see also* LATENT HEAT OF FUSION).

Heat of vaporization (L_v)

[general, thermodynamics] The quantity of heat per unit mass required to vaporize a LIQUID substance while at its condensation temperature $Q = \pm mL_v$, characteristic for each material. For instance, water at 100°C (the BOILING POINT), under ATMOSPHERIC PRESSURE, has a heat of vaporization of $L_v = 2.259 \times 10^3$ J/g (*see also* LATENT HEAT OF FUSION) (*see* Figure H.21).

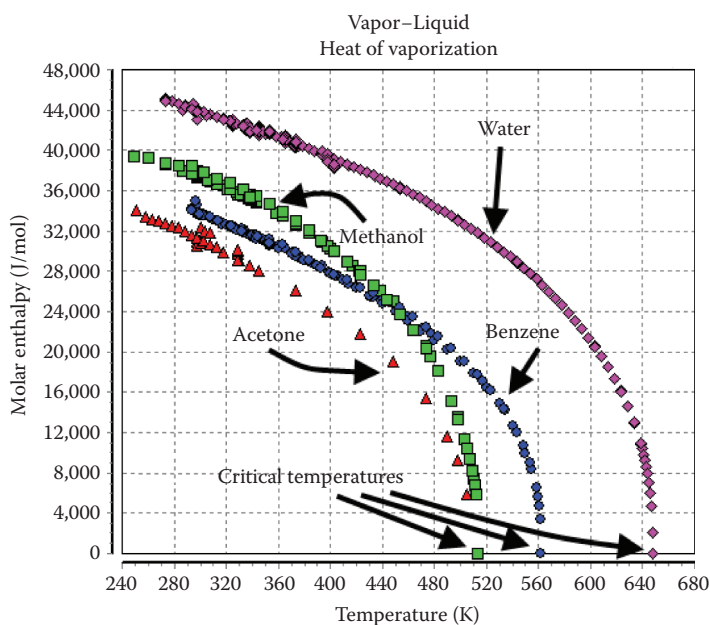


Figure H.21 Diagram of the temperature dependence of the heat of vaporization for several media.

Heat transfer

[thermodynamics] Using the **EQUATION-OF-STATE** the **HEAT TRANSFER** between two states of a system is defined as $dQ = C_v dT + (RT/V)dV$, where Q is the heat, C_v the **SPECIFIC HEAT**, T temperature, V the volume of the phenomenon, and R the universal **GAS** constant; $R = 0.082057$ liter atm/mol K, $R = 8.314472$ J/mol K, $R = 8.205745$ m³ atm/mol K, $R = 62.36367$ liter Torr/mol K (alt. liter mmHg/mol K).

Heavy water

[general] The popular name for water, which is composed of two atoms of deuterium and one **ATOM** of oxygen.

Heisenberg, Werner Karl (1901–1976)

[atomic, computational, general, nuclear] A physicist and mathematician from Germany known for the introduction of the **UNCERTAINTY PRINCIPLE** in 1927; the location (y) of a phenomenon with momentum $p = h/\lambda$ ($h = 6.62606957 \times 10^{-34}$ m²kg/s the Planck's constant and λ the wavelength associated with the phenomenon), specifically applied to measure the atomic configuration. Alternatively, object with mass m and velocity v has a momentum $p = mv$. The object/phenomenon can only be defined with limited confidence $\Delta p_y \Delta y \geq h/2\pi$ (see [Figure H.22](#)).

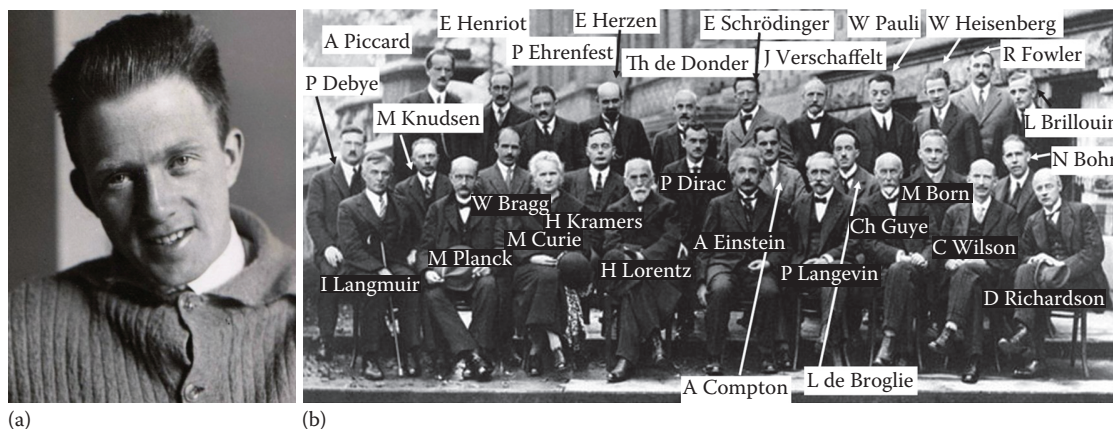


Figure H.22 (a) Werner Karl Heisenberg (1901–1976) and (b) Werner Heisenberg at the 1927 Solvay conference. (Courtesy of Friedrich Hund.)

Heisenberg's uncertainty principle

[computational, general, nuclear, quantum] See **UNCERTAINTY PRINCIPLE**.

Heliocentric

[astronomy/astrophysics, general] A description of the organization of our planetary system placing the Sun in the center of the orbiting 8, respectively, 9 planets. The International Astronomical Union may decide to exclude Pluto as a **PLANET** due to the fact that is too small and there is additional debris in its orbit that is

significant in size to reclassify Pluto as a dwarf planet, thus reducing the number of planets from 9 to 8. The HELIOCENTRIC system was developed by NICOLAUS COPERNICUS (1473–1543) and published in 1543 as *De revolutionibus orbium coelestium libri sex*, in contrast with the GEOCENTRIC model, assuming the EARTH as the center of the planetary system, described by PTOLEMAEUS (third century BC–~130 BC), and most likely dating back even farther (see [Figure H.23](#)).

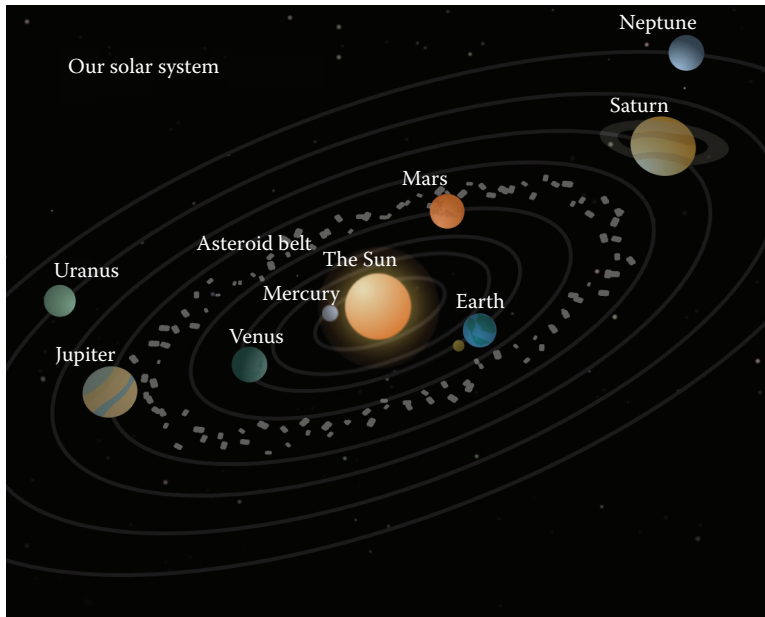


Figure H.23 The solar system with the Sun as the center and the planets in orbit around the Sun.

Heliographic latitude

[astronomy/astrophysics, general, geophysics] The solar LATITUDE. The angular DISTANCE from the solar geographic equator with respect to the reference frame of the SOLAR SYSTEM (average plane of all PLANETARY ORBITS), based on the SPIN and PRECESSION.

Helmholtz, Hermann Ludwig Ferdinand von (1821–1894)

[acoustics, electromagnetism, energy, fluid dynamics, optics, thermodynamics] A mathematician, physicist, physiologist, and anatomist from the Prussian Empire: Germany. A German scientist with a broad range of contributions in science and technology. Apart from being a theorist, Helmholtz was also an inventor. In 1850, Helmholtz introduced the design for an ophthalmoscope, and in 1856, he published the MECHANICS of reshaping the LENS for accommodation of the EYE in his *Handbuch der Physiologischen Optik*. Helmholtz's scientific career was quite prolific and presented, for instance, his theoretical review of rotational MOTION (e.g., vortices) in 1858, next to his experimental work and theoretical proof of electric induction with the HELMHOLTZ COILS in addition to an elaborate analysis of acoustical phenomena, including the HELMHOLTZ RESONATOR. Helmholtz's primary contribution to science and engineering is the fact that he provided the proof that EUCLIDEAN GEOMETRY is not the only theoretical approach to the description of conceptual and physical space. His second most noteworthy influence is in field theory, moving away from PARTICLE interaction. He also formulated ENERGY CONSERVATION, as well as the VORTEX

equations for FLUID DYNAMICS. Additional work by Helmholtz is in the area of THERMODYNAMICS with his parametric description of free energy (i.e., HELMHOLTZ FREE ENERGY) (see [Figure H.24](#)).



Figure H.24 Hermann Ludwig Ferdinand von Helmholtz (1821–1894).

Helmholtz coil

[energy, thermodynamics] A combination of two or more identical small CROSS SECTION annular coils with common axis, lined up at variable DISTANCE connected in series. This design is intended to produce a more uniform MAGNETIC FIELD than a single coil without the specific need for a SOLENOID, which is significantly larger. In the optimal arrangement, the distance separating the two coils is equal to the radius of the coils, with negligible fluctuations in the virtually uniform magnetic field measured in the core (see [Figure H.25](#)).

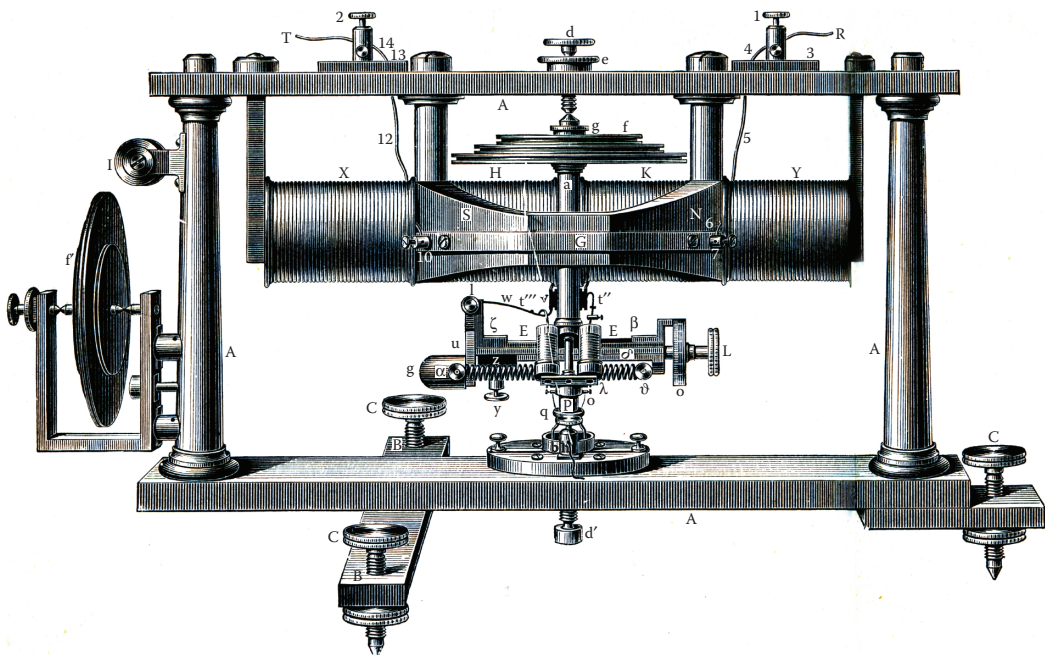


Figure H.25 Drawing of the Helmholtz coil design.

Helmholtz decomposition

[computational, fluid dynamics] A fundamental part of vector calculus. In three-dimensional space, the vector field composed of sufficiently smooth, rapidly decaying vectors can be decomposed into the sum of two “orthogonal” components, one consisting of an **IRROTATIONAL (CURL-FREE) VECTOR FIELD** and the second segment composed of rotational (divergence-free) or solenoidal vector field. The vector ($\vec{V}$) decomposition is formulated as follows: $\vec{V} = -\nabla\mathbb{C} + \nabla \times \mathbb{D}$, with the curl-free component $\mathbb{C}$ and divergence-free component $\mathbb{D}$.

Helmholtz energy

[acoustics, energy, thermodynamics] Work involved in isothermal irreversible processes. It was introduced by **HERMANN LUDWIG FERDINAND VON HELMHOLTZ** (1821–1894) in 1882. It was defined by $A_\sigma = U_\sigma - TS_\sigma$, where U_σ is the surface excess ENERGY, T is the thermodynamic temperature, and S_σ is the surface excess entropy. It is also known as **HELMHOLTZ FREE ENERGY** (*also see* **GIBBS FREE ENERGY**).

Helmholtz free energy (F)

[thermodynamics] $F = U - TS$, where U is the internal ENERGY, T is the temperature, and S is the entropy of the system, respectively. In an isothermal process, the internal energy does not change for an **IDEAL GAS**, which makes the Helmholtz free energy most appropriate to work within the energy balance.

Helmholtz resonator

[acoustics, energy, thermodynamics] A rigid acoustic apparatus with a minimum of one **ORIFICE**. The design of the device results in specific **RESONANCE** frequencies due to the material selection, dimensions, and placement of the openings. The design was developed by **HERMANN LUDWIG FERDINAND VON HELMHOLTZ** (1821–1894) for spectral analysis of musical tones. The natural frequency that the device can support is a function of the respective dimensions and properties and is described in detail under **NATURAL FREQUENCY**.

Henry, Joseph (1797–1878)

[electromagnetism, general] An electrical engineer and physicist from the United States. The work of Henry on electromagnetic induction lends his name to the **MAGNETIC FIELD** strength as the Henry (H). Joseph Henry described the relationship between electric fields and magnetic fields in the 1820s. Simultaneously in the United Kingdom, **MICHAEL FARADAY** (1791–1867) discovered and described similar correlations. Based on the work of both Joseph Henry and Michael Faraday, the integral theories of electromagnetic **WAVE** propagation were developed by **JAMES CLERK MAXWELL** (1831–1879) (see [Figure H.26](#)).



Figure H.26 Joseph Henry (1797–1878).

Henry, William (1774–1836)

[biomedical, chemical, fluid dynamics, thermodynamics] A chemist from the United Kingdom/Great Britain, also a mechanical engineer. William Henry is known for his description with respect to the solubility of substances (see [Figure H.27](#)).



Figure H.27 William Henry (1774–1836). (Courtesy of the trustees of the British Museum, London.)

Henry, unit (H)

[general] Unit for the inductance of a MAGNETIC coil, that is, SOLENOID based on the definition that one Henry provides a magnetic flux of 1 Weber under the influence of a current of 1 AMPÈRE.

Henry's constant

[chemical, thermodynamics] The solubility α_{sol} for the SOLUTE (*also* **HENRY'S LAW COEFFICIENT**), representing the concentration of dissolved gas ($[C_{\text{Dissolved}}]$) in a LIQUID proportional to the partial pressure of the GAS (P_{gas}), expressed by $[C_{\text{Dissolved}}] = \alpha_{\text{sol}} P_{\text{gas}}$.

Henry's law

[biomedical, chemical, fluid dynamics, thermodynamics] The solubility of substances expressed by WILLIAM HENRY (1774–1836) in 1803. Henry's law is a representation of the concentration of dissolved gas ($[C_{\text{Dissolved}}]$) in a liquid in proportion to the partial pressure of the gas (P_{gas}), expressed by $[C_{\text{Dissolved}}] = \alpha_{\text{sol}} P_{\text{gas}}$. The DIFFUSION coefficient in LIQUID phase is related to this by the Krogh diffusion for liquid phase solutes $K_{\text{Diff}} = \alpha_{\text{sol}} D_{\text{diff}}$, where α_{sol} is the solubility for the SOLUTE (Henry's law coefficient), and D_{diff} is the diffusion coefficient in GAS PHASE. One example of Henry's law is the dissolved carbon dioxide in carbonated drinks (i.e., soda's). Another interpretation is in the representation of the CHEMICAL POTENTIAL ($\mu_{i\chi}$, where i indicates the constituent within a SOLUTION and χ the PHASE; gas: g or liquid: ℓ) of a solution providing Henry's law $\mu_{1g} P_{\text{gas}} = \mu_{1\ell} \mathcal{H}_{1\ell}(T, P)$, where $\mathcal{H}_{1\ell}(T, P) = P_{\text{sat},11}(T) \exp\{[\lambda_{1\ell}(T, P) - \mu_{11,\ell}(T, P_{\text{sat},11}(T))]/RT\}$ is the HENRY'S CONSTANT for the SOLUTION of solute 2 in liquid phase under pressure P and temperature T , with $\lambda_{1\ell}(T, P)$ a constant that defines the boundary conditions of the integration over the partial pressure of the potential equivalent gas equation $(\partial \mu_{1\ell} / \partial \ln(\mathcal{Y}_{1\ell}))_{T,P} = RT$, where $R = 8.3145 \text{ J/molK}$ is the universal GAS constant and $\mathcal{Y}_k = n_k/n = (x_k/M_k)/(\sum_{\ell=1}^r x_{\ell}/M_{\ell})$ is the MOLE fraction of the dissolved constituent k , with M_{ξ} the mean MOLECULAR WEIGHT of solute ξ , for the amount of constituent n_k summing to a total of solutes $n = \sum_{k=1}^r n_k$, x_{ξ}

the fractional mass for constituent ξ (Note: $\sum x_\xi = 1$), P_{ji} the molar partial pressure of constituent j in solution (also see **VAN'T HOFF**, **JACOBUS HENDRICUS**, and **OSMOTIC PRESSURE**).

Herschel, Friedrich Wilhelm (Frederick William), Sir (1738–1822)

[astronomy, fluid dynamics, general] A scientist and astronomer from Germany. Friedrich Herschel was a musician interested in scientific exploration. He examined **RADIATION** with the assistance of a **THERMOMETER**, thus eluding to the heat properties of infrared radiation in the early concept stage around 1800. He discovered that longer wavelengths (**RED** and beyond the red) induce higher temperatures and as such discovered infrared light, indicating that the solar radiation consists approximately 50% of invisible (**INFRARED**) radiation. He also discovered the neighboring **Splinter Galaxy** at approximately 5×10^7 lightyears from our **SOLAR SYSTEM**. He primarily acquired fame for his discovery of the **PLANET Uranus**. He investigated the effect of various bandwidths of the **ELECTROMAGNETIC SPECTRUM** with respect to induced temperature rise by exposing a thermometer to sunlight filtered by colored **GLASS** and other **OPTICS**.

Herschel, Winslow Hobart (1873–1940)

[fluid dynamics, general, mechanics] Because of the steady-state flow, the phenomenon can be described with a model that is spatially nonlinear as well as temperature and location dependent. The shear stress resulting from **BLOOD** flow through a vessel can be described using the **Herschel–Bulkley** approximation to model blood as a flow medium. This gives the **SHEAR STRESS** (τ_s) as a function of flow with flow velocity $u(r, t)$ as a function of time t and radius r as $\tau_s = \mu_y'^{1/n} (\partial u(r, t) / \partial r)^{1/n} + \mu_y'$ under the condition $\tau_s \geq \tau_y$, while $\partial u(r, t) / \partial r = 0$ for $\tau_s < \tau_y$, τ_y' is the **HERSCHEL–BULKLEY YIELD STRESS** and μ_y' is the **HERSCHEL–BULKLEY COEFFICIENT OF FRICTION**. The shear rate is also dependent on the vessel diameter, the **FLOW** velocity itself, next to the flow pulsation frequency along with other system condition parameters. These dependencies can be defined either by means of the mechanical **COMPLIANCE** of the vessel or by the mechanical impedance as a function of the time-dependent flow traversing a compliant vessel.

Herschel–Bulkley coefficient of friction

[biomedical, fluid dynamics, mechanics] Generally the **Herschel–Bulkley** flow describes the situation of a nonlinear **VISCOSITY** that is associated with the movement of a medium that is a plasticide, with a threshold that needs to be exceeded before flow is initiated introduced by Ronald Bulkley (1895–1985), based on the work of, and in collaboration with, **WINSLOW HOBART HERSCHEL** (1873–1940).

Herschel–Bulkley fluid

[biomedical, fluid dynamics, mechanics] Non-Newtonian fluid (colloid **SOLUTION**) that is defined by a threshold yield stress (τ_y) before flow can be established. Examples of this type of media are jelly and jam and other food products, cement, mud sludge encountered during drilling for **OIL**, magma/lava, mud, toothpaste, composites (**PLASTICS**), pulp, and paint to name a few. The concept was introduced in 1926 by Ronald Bulkley (1895–1985) and **WINSLOW HOBART HERSCHEL** (1873–1940). The **Herschel–Bulkley** model is especially useful in the formation of a model for a dampener such as found in a **SHOCK ABSORBER**, mainly due to the inherent **HYSTERESIS** of the **FLOW**. Since **APPARENT VISCOSITY** (η_{app}) is a function of the

relationship between shear stress and shear rate, the VISCOSITY will change depending on the shear rate (see Figure H.28).

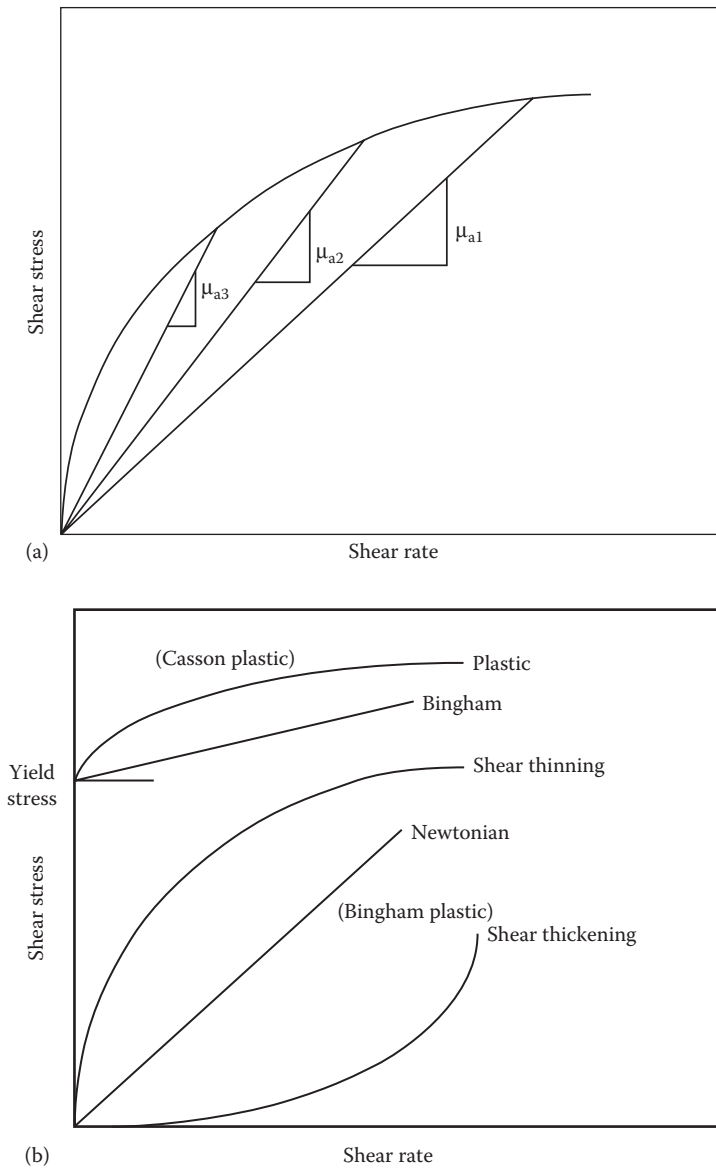


Figure H.28 (a) Illustration of the change in viscosity with applied shear rate under the Herschel–Bulkley model and (b) various viscous models, in comparison to the Herschel–Bulkley model.

Herschel–Bulkley yield stress (σ_{yield})

[biomedical, fluid dynamics, mechanics] The threshold for stress below which no FLOW is possible for a “plastic” fluid. This is a dynamic phenomenon, since the stress is influenced by the applied force (i.e., pressure). Its applications are specifically in RHEOLOGY. Below this threshold, the FLUID can be suspended,

such as ketchup not willing to flow from a bottle held upside down; in this manner, the fluid can support its own weight by shear stress to the WALL.

Hertz, Heinrich Rudolf (1857–1894)

[acoustics, computational, electromagnetism, general] A German physicist and experimentalist. As one of the pioneers in the transmission and reception of RADIO waves, his name became attached to the WAVE phenomenon. His experiments illustrated the commonality between radio waves and light waves in REFLECTION, REFRACTION, and transmission, tying all together as ELECTROMAGNETIC RADIATION. Hertz's theoretical work confirmed his experimental model after reinterpreting the Maxwell's wave equations, pertaining to electromagnetic waves, eliminating the notion of the ETHER proposed by JAMES CLERK MAXWELL (1831–1879) (see [Figure H.29](#)).



Figure H.29 Heinrich Rudolf Hertz (1857–1894).

Hertz (Hz), unit

[general] Unit for number of fluctuations per SECOND. The unit Hertz was named after the contributions to RADIO wave and experimental verification of the MAXWELL EQUATIONS by HEINRICH RUDOLF HERTZ (1857–1894).

Hertzsprung–Russell diagram

[astronomy/astrophysics] An evolutionary log–log plot of the luminosity of a STAR (L_*) against the effective surface temperature of a star, specifically in reference to our solar parameters: solar luminosity ($L_\odot$) and solar radius ($R_\odot$), and solar mass ($M_\odot$; also expressed in density $\rho_\odot$). The diagram was designed by Ejnar Hertzsprung (1873–1967) from Denmark and HENRY NORRIS RUSSELL (1877–1957) from the United States in 1923. The implied ENERGY configuration will indicate the “locations” for ignition of hydrogen, helium, and carbon, respectively, and the relative effects in comparison to NEUTRINO energy loss based on the

FISSION processes (see **H-BOMB** and **FISSION**). Specifically low-mass stars, including the Sun ($0.08M_{\odot} < M < 8M_{\odot}$), experience hydrogen and helium burning stages (see [Figure H.30](#)).

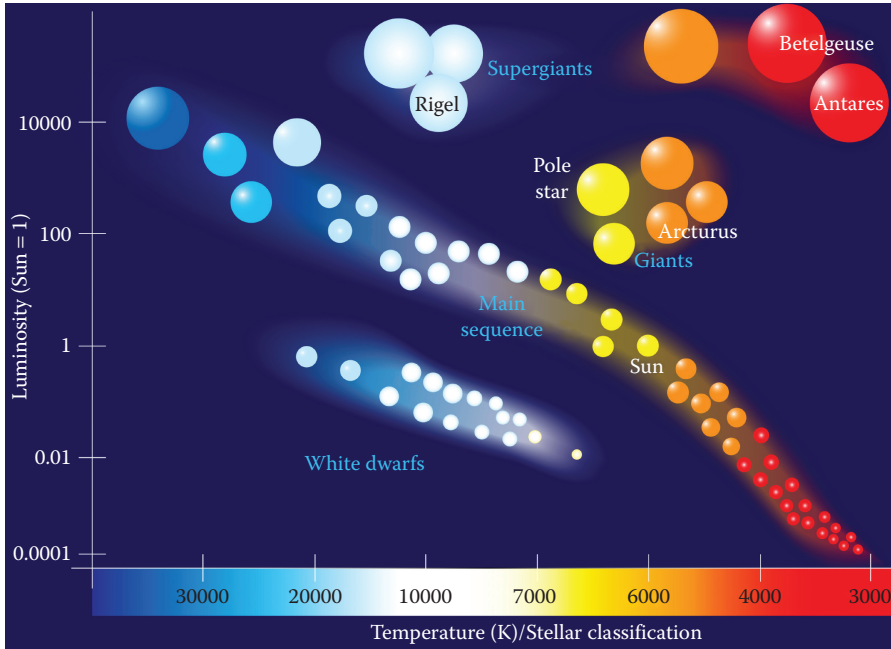


Figure H.30 Hertzsprung–Russell diagram.

Hessian

[computational] A mathematical tool in spectral function analysis. The second-order gradient of a real function that is twice differentiable with respect to its vector domain in κ -dimensional space:

$$\mathbb{S}^{\kappa} : \nabla^2 f(x) \equiv \begin{array}{cccc} \frac{\partial^2 f(x)}{\partial x_1^2} & \frac{\partial^2 f(x)}{\partial x_1 \partial x_2} & \dots & \frac{\partial^2 f(x)}{\partial x_1 \partial x_k} \\ \frac{\partial^2 f(x)}{\partial x_2 \partial x_1} & \frac{\partial^2 f(x)}{\partial x_2^2} & & \frac{\partial^2 f(x)}{\partial x_2 \partial x_k} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f(x)}{\partial x_k \partial x_1} & \frac{\partial^2 f(x)}{\partial x_k \partial x_2} & \dots & \frac{\partial^2 f(x)}{\partial x_k^2} \end{array}$$

Applications are found particularly in spectral analysis. The second-order derivative provides significant RESOLUTION enhancement, particularly with respect to the identification of the slope of a curve as well as locating extremes based on experimental data. The use of the Hessian transforms the analysis from an absolute algorithm to a relative algorithm with increase in sensitivity up to an order of MAGNITUDE.

Hexagonal closed packed (hcp) structure

[condensed matter, solid-state] Hexagonal LATTICE structure, for example, cobalt (Co).

Higgs, Peter Ware (1929–)

[atomic, computational, energy, general, solid-state] A physicist from Great Britain. Peter Higgs is known for his work on the **ELECTROWEAK FORCE**, specifically the discontinuities or broken symmetry in this theoretical concept. Other work of Higgs was on **ELEMENTARY PARTICLES**, in particular the elusive **HIGGS BOSON** and the description of the mass of the **W** and **Z** bosons (see [Figure H.31](#)).



Figure H.31 Peter Ware Higgs (1929–). (Courtesy of Gert-Martin Greuel—Mathematisches Institut Oberwolfach, Oberwolfach, Germany.)

Higgs boson

[atomic, general, solid-state] An elementary particle that has been introduced from a theoretical standpoint in 1964. The Higgs boson is a particle that conforms to the **GAUGE THEORY** concepts. The **PARTICLE** was named after **PETER WARE HIGGS** (1929–), one of the theoretical physicists involved in the development of the concept. Peter Higgs' work was in collaboration with Gerald Stanford Guralnik (1936–2014), and in parallel with the works of Robert Brout (1928–2011) and François Englert (1932–) in Belgium, next to Carl Richard Hagen (1937–) in the United States and Sir Thomas Walter Bannerman Kibble (1932–) in the United Kingdom. The Higgs boson in principle has zero **SPIN** and positive **PARITY**. The particle has been tentatively verified as recent as 2013.

Higgs mechanism

[atomic, computational, energy, general, solid-state] A gauge transformation applied to massless bosons with **SPIN 0**. The gauge transformation rectifies the loss of symmetry in the Lagrangian describing the **WEAK INTERACTION** in the **BOSE CONDENSATE**, consisting of **SCALAR** fields.

High-energy physics

[computational, electromagnetism, energy, general, thermodynamics] With the increasing elementary structure of the **ATOM** unfolding, there was a growing need for a description that could capture the phenomena in the **ELEMENTARY PARTICLES**. The quarks forming the elementary **PARTICLE** that under **STRONG FORCE** form **NEUTRON**, pions, protons, and the like in contrast to the complementary subnuclear group of leptons that do not form strong force ties such as electrons and the **NEUTRINO** among others. These subnuclear particles will be described by the **QUANTUM ELECTRODYNAMIC** theory in only limited cases, but it forms a general basis. In addition to the **WEAK FORCE**, which is described by **QUANTUM** electrodynamic theory as outlined by **ENRICO FERMI** (1901–1954) in 1932, **HIDEKY YUKAWA** (1907–1981) postulated that the **STRONG FORCE** relies on

the exchange of a VIRTUAL BOSON around 1934. The fact that SUBATOMIC structures are high ENERGY is conveyed by the fact that second- and third-generation ELEMENTARY PARTICLES: LEPTONS and QUARKS can have energy in excess of $11\text{GeV} = 2\mu\text{J}$.

Hilbert, David (1862–1943)

[computational] A mathematician from Germany (Prussian Empire). David Hilbert was instrumental in documenting and verifying a broad range of elementary mathematical concepts and provided a foundation for modern mathematical analysis (see [Figure H.32](#)).



Figure H.32 David Hilbert (1862–1943) in 1886.

Hilbert space (H_X)

[quantum, theoretical] The dot product of the continuous set of function in SOLUTION to the WAVE EQUATION that is in COMPLIANCE with the equivariance condition, designed by DAVID HILBERT (1862–1943). The equivariance condition assumes equivalence of gravitational and inertial mass. This defines the vectors of the QUANTUM mechanical state density matrices (see [Figure H.33](#)).

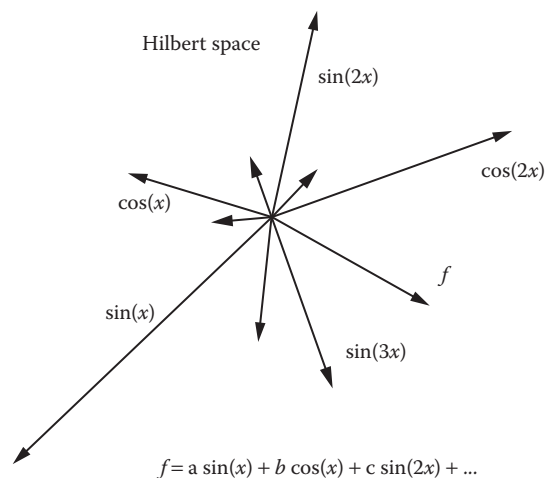


Figure H.33 Illustration of the Hilbert space concept.

Hill, Archibald Vivian (1886–1977)

[biomedical, chemical, mechanics] A physiologist and scientist from Great Britain. Archibald Hill contributed significant insight into the ENERGY exchange, kinetics, and work performed by muscles.

Hill coefficient " n_H "

[biomedical, chemical] Probabilistic number of LIGAND molecules binding sites in the chemical reaction. It is also defined as an interaction coefficient for a chemical reaction. The quantitative number of bindings is based on the chemical structure and VALENCE of the constituents of the reaction, rather than the estimated number of binding sites (see Figure H.34).



Figure H.34 Archibald Vivian Hill (1886–1977) in 1925. (Courtesy of the History of Medicine [NLM], Bethesda, Maryland.)

Hill equation

[biomedical, chemical] The ratio of protein that is in a complex chemical bond with a LIGAND, for instance, the protein hemoglobin bound to oxygen to form oxyhemoglobin, introduced by ARCHIBALD VIVIAN HILL (1886–1977) in 1910. This process will reach a certain SATURATION based on the oxygen supply during exposure in the lung during inhalation. In (bio-)chemical reactions, the equilibrium is described by a rate constant ($K_d = [P][L]^{n_H} / [P : L_{n_H}]$, where $[P]$ is the protein concentration, $[L]$ is the ligand concentration {in biology often oxygen (O_2)}, and $[P : L_{n_H}]$ is the protein:ligand complex concentration; for instance, oxygen bound to hemoglobin (Hb)), with the HILL COEFFICIENT: " n_H " representing the number of ligand molecules binding sites in the chemical reaction (for instance, n_H can be as high as 4 for oxygen binding to hemoglobin: $Hb + 4O_2 \rightleftharpoons Hb(O_2)_4$). Note that the oxyhemoglobin reduces to hemoglobin when flowing through the tissue where the partial pressure for oxygen is lower (depleted from metabolic action). The ratio of ligand binding is defined as $Y = \text{protein : ligand complex} / \text{total protein} = [P : L_{n_H}] / \{[P] + [P : L_{n_H}]\} = [L]^{n_H} / \{K_d + [L]^{n_H}\}$, which represents, for instance, $Y = 0.3$ for 30% saturation.

Hipparchus (190–125 BC)

[astronomy, general] An astronomer and mathematician from Turkey/Greece. Hipparchus collected an impressive amount of critical astronomical observations that he subjected to geometric calculations. Hipparchus is by some considered to be the "father of trigonometry." He calculated and determined the eccentricity of the MOON orbit and its "long axis" of the elliptical orbit. He documented 1025 bright stars and named them; however, some may be attributed to Naburiannu (~500 BC) and Kidinnu (~400 BC). In his time, he calculated the DISTANCE to the Sun to be roughly 1200 times

the radius of the EARTH and the distance to the Moon (relatively accurately) to be 59 times the radius of Earth (see [Figure H.35](#)).



(a)



(b)

Figure H.35 (a) Picture of stamp commemorating Hipparchus (190–125 BC) with an impression of his likeness, and (b) picture of the armillary sphere designed by Hipparchus, celestial sphere model of objects in the sky with the Earth as center.

Hippocrates of Cos (460–377 BC)

[biomedical, general] A Greek physician who introduced that credo that a doctor shall not harm a person based on the knowledge acquired in experimental observation and anatomical studies. He proposed as one of the first that a disease is an environmental factor, not a punishment of god/the gods. Hippocrates introduced traction to treat chiropractic ailments, using a mechanical bed. His philosophy is now recognized under the Hippocratic Oath, a promise physician still take upon completion of their medical university training (see [Figure H.36](#)).



Figure H.36 Chest sculpture with impression of what Hippocrates of Cos (460–377 BC) may have looked like.

Hoar frost

[general, thermodynamics] Frozen ADHESION of water vapor. Hoarfrost often creates a fine mesh of water crystal tentacles, in appearance resembling a forest of minuscule pine trees on the surface of the cold object (see [Figure H.37](#)).



Figure H.37 Hoar frost, freezing water vapor. Sometimes also known as Rime frost. (Courtesy of Tony Garramone.)

Hodgkin, Alan Lloyd, Sir (1914–1998)

[biophysics, chemical, computational, electromagnetism, energy] A physicist and biomedical engineer from Great Britain. His work with SIR ANDREW FIELDING HUXLEY (1917–2012) and supporting efforts on the neural transmitter interface by JOHN CAREW ECCLES (1903–1997) revealed the mathematical/chemical description of the ACTION POTENTIAL in a depolarizing CELL (e.g., MUSCLE cell or nerve cell [NEURON]). Their work resulted in the Nobel Prize in Physiology in 1963 (see [Figure H.38](#)).



Figure H.38 Sir Alan Lloyd Hodgkin (1914–1998).

Hodgkin, Dorothy Mary (1910–1994)

[chemical, imaging] A chemist from Egypt. She was also known as Dorothy Crowfoot Hodgkin. Dorothy Hodgkin received the Nobel Prize in Chemistry in 1964 for her development of the process and technique of protein crystallography (see [Figure H.39](#)).



Figure H.39 Dorothy Mary Hodgkin (1910–1994).

Hodgkin–Huxley model

[biomedical, computational, electronics] A time-dependent membrane potential equation used to describe the construction of the ACTION POTENTIAL for a depolarizing CELL MEMBRANE. The Hodgkin–Huxley model is a variation on the steady-state multi-ion Goldman equation. The Hodgkin–Huxley model is the result of the work by ALAN LLOYD HODGKIN (1914–1998) and ANDREW FIELDING HUXLEY (1917–2012) in 1952. The Goldman equation in turn was an EXPANSION to the single-ion steady-state ion potential described by WALTHER HERMANN NERNST (1864–1941), the NERNST POTENTIAL, which was based on the DONNAN EQUILIBRIUM, introduced around 1905. In general, the steady-state and time-dependent membrane potential is based on the ION concentration in the intracellular and extracellular space for sodium (Na^+), POTASSIUM (K^+), and chlorine (Cl^-), with additional contributions from calcium (Ca^{2+}) and magnesium (Mg^{2+}). Alan Hodgkin and Andrew Huxley derived their model from the experiments they performed on the giant squid axon. The giant squid axon is a large nerve cell (diameter 1 mm [100 times the diameter of any mammalian nerve cell]; length 10 cm) that can easily be probed and measured for ion concentration and localized electrochemical potential. The giant squid axon in the mantle of the North Atlantic squid was discovered by Leonard Worcester Williams (1875–1912) in 1909, but John Zachary Young (1907–1997) made the scientific community aware of its experimental importance in 1936. The model describes the ion migration through three channels, one for each of the main ions (Na^+ , K^+ , and Cl^-), leading up to the ACTION POTENTIAL. The ion transport is mediated by gap junctions. Based on existing electrical parameters, specifically OHM'S LAW, the ion currents were defined as $I_{\text{Na}} = g_{\text{Na}} (V - V_{\text{Na}})$, $I_{\text{K}} = g_{\text{K}} (V - V_{\text{K}})$, and $I_{\text{Cl}} = g_{\text{Cl}} (V - V_{\text{Cl}})$, where the chlorine current is generally represented as a combined ion leakage current (of predominantly negative ions) $I_{\ell} = g_{\ell} (V - V_{\ell})$, where g_i the “conductance” for the ion is a representation of the ION MOBILITY, inversely related to the RESISTANCE. In this, V_i is the Nernst potential for the respective ion(s) and V is the MEMBRANE potential. The conductance was modeled by Hodgkin and Huxley represented by the theoretical maximum ($\bar{G}_i$) multiplied by rate factors (α_n and β_n) that were all based on heuristic determination. For instance, for potassium: $G_{\text{K}} = \bar{G}_{\text{K}} n^4$, where $0 \leq n \leq 1$ is a scaling factor with boundary condition $dn/dt = \alpha_n (1 - n) - \beta_n n$, where $\alpha_n = 0.01 \{ (V + 10) / [\exp((V + 10)/10) - 1] \}$ and $\beta_n = 0.125 \exp(V/10)$. Equivalently for sodium $g_{\text{Na}} = \bar{g}_{\text{Na}} m^3 b$, with boundary conditions $dm/dt = \alpha_m (1 - m) - \beta_m m$, and $db/dt = \alpha_b (1 - b) - \beta_b b$; $0 \leq m \leq 1$, $0 \leq b \leq 1$ scaling factors, with best fit: $\alpha_m = 0.1 \{ (V + 25) / [\exp((V + 25)/10) - 1] \}$ and $\beta_m = 4 \exp(V/18)$, respectively, $\alpha_b = 0.07 \exp(V/20)$

and $\beta_m = [\exp((V + 30)/10)11]^{-1}$. The total Kirchhoff current summation for all respective ion-currents is now $I = I_K + I_{Na} + I_\ell = C_m(dV/dt) + \bar{\mathcal{G}}_K n^4 (V - V_K) + \bar{\mathcal{G}}_{Na} m^3 h (V - V_{Na}) + \bar{\mathcal{G}}_\ell (V - V_\ell)$, where C_m is the MEMBRANE CAPACITANCE. The individual ion FLOW current density (J_i) across the gates in the membrane is based on the NERNST-PLANCK DIFFUSION EQUATION, using the DIFFUSION coefficient of the respective ions D_i , expressed as $\bar{J}_i = -D_i (\bar{\nabla} C_{m,i} + (C_{m,i}/\gamma_i^{\text{charge}}) \bar{\nabla} V)$, incorporating the ionic charge distribution by means of $\gamma_i^{\text{charge}} = RT/FZ_i$ (R the universal GAS constant, F the Faraday's constant, Z_i the ion VALENCE, and T the ABSOLUTE TEMPERATURE). The action potential is derived from the Crank-Nicholson differential equation $(1/r_a) \nabla^2 V = C_m(dV/dt) + I_K + I_{Na} + I_{Ca} + I_\ell + I_{\text{stimulus}}$, where r_a is the electrical resistance for the intracellular medium (ion migration) and I_{stimulus} is the stimulation current (originating from an influence on the membrane). The stimulant current can result from the chemical imbalance induced, for instance, by means of the interaction of light on BACTERIORHODOPSIN, pressure applied to a pressure sensing cell, chemicals on taste buds, and so on.

Hodgson number ($H = fV\Delta P/Q\bar{P}$)

[fluid dynamics, thermodynamics] A dimensionless time for a system in alternating MOTION, describing the time constant during pulsation period for the system, where f is the frequency, V the characteristic volume, ΔP the pressure gradient, Q the volumetric flow rate, and $\bar{P}$ the average static pressure. The Hodgson number applies specifically to unsteady pulsating gas FLOW and generally to momentum transfer. The Hodgson number can provide a useful means of predicting errors in metered flow recordings, for instance, at a pulsating compressor, at the location of the meter such as a venture or ORIFICE.

Holography

[general, optics] An interference IMAGE that is constructed by means of laser scanning of two images on layers of photographic plates that will provide the same three-dimensional appearance when illuminated with a small, narrow ANGLE emission light source. The mechanism to capture the image consists of a three-dimensional open weave grid coated with photographic emulsion (e.g., silver chloride, as found on regular photographic film). The image is formed by means of INTERFERENCE, retaining the PHASE information of the electromagnetic OSCILLATION next to the AMPLITUDE information based on the "reflectiveness" of the object. The scanning and object illuminating LIGHT SOURCE is by requirement coherent and as such requires the use of laser light. The laser beam is split by a beam splitter in a reference beam and a probing/imaging beam, which are recombined in the three-dimensional PHOTOGRAPHIC PLATE, writing an image in three dimensions. The viewing of the hologram can be performed in several different ways, one is looking at the plate itself from where the image is appearing as outlined by the frame only, not anchored to the plate itself. The image formation itself performs an interference scheme that appeals to the stereoscopic VISION aspect of our two eyes and subsequent cerebral interpretation. In theory, every cubic millimeter of the photographic mesh contains an angular view of the entire object, providing a wealth of redundancy. Alternatively, a holographic projection can be produced free from the photographic film mesh, appearing in free space. The requirements for the viewing light source do not include coherence *per se*, nor does it need to be monochromatic. However, the crispness of the image in free-space will be more well defined when the source is more tightly defined. The concept of holography

was invented by the physicist DENNIS GABOR (1900–1979) from Hungary in 1947 for which he received the Nobel Prize in Physics in 1971 (see [Figure H.40](#)).



(a)



(b)

Figure H.40 (a,b) Artist rendering of the future of holography.

Homeostasis

[biomedical] Refers to the maintenance of the parameters with respect to all aspects of the internal cellular environment within tolerable limits. Cells carefully regulate their intracellular ionic concentrations, as well as the water level, to ensure that no osmotic pressures arise. As a consequence, the major ions Na^+ , K^+ , Cl^- , and Ca^{2+} have different concentrations in the extracellular and intracellular environments. Additionally, the ENERGY consumption of the CELL with respect to survival as well as providing a function (e.g., MUSCLE) requires a balance of nutrients, oxygen, waste, energy, and water, reducing down to maintaining the ATP level. The homeostasis regulates the energy, chemical, and FLUID balance within a cell, between similar cells, between different cells, between different organs, and across the CELL MEMBRANE.

Hooke, Robert (1635–1703)

[biomedical, general, mechanics, optics, solid-state] A physicist, scientist, and engineer from Great Britain. In 1660, Robert Hooke investigated the phenomenon of COLOR separation on thin transparent films, such as the colorful soap BUBBLE. This study provided him with the rudimentary theoretical conviction that light is a WAVE. SIR ISAAC NEWTON (1642–1727) used Hooke's information and proposed a dual nature for light, both with PARTICLE (mechanical) properties as well as with wave properties. Furthermore, both THOMAS YOUNG (1773–1829) and AUGUSTIN-JEAN FRESNEL (1788–1827) confirmed the hypothesis of Robert Hooke not until the early 1800s. In 1665, Robert Hooke proposed the atomic model of MATTER, based on crystalline structures and apparent transparency, indicating holes between the SOLID-STATE nature. This observation was confirmed by his description of MIXING one GLASS of ALCOHOL and one glass of water, which form less than two glasses of mixture, apparently the one is slipping between the other. The full context of the atomic model was not confirmed until JOHN DALTON (1766–1844) in the early 1800s provided a detailed description of chemical reactions. In 1676, Robert Hooke published his SPRING FORCE theory, proportional to the displacement, known as HOOKE'S LAW (see Figure H.41).



Figure H.41 Robert Hooke (1635–1703); no known surviving images of Robert Hooke are in existence. (Artist rendering; Courtesy of Rita Greer.)

Hooke's law

[biomedical, general] The mathematical relation between stress (S_n) and STRAIN (ϵ_n) resulting from an axial force. This concept was introduced in 1676 by ROBERT HOOKE (1635–1703). Graphically, this is represented in the slope of the linear part of the stress–strain curve, defined as the YOUNG'S MODULUS (Y_n) of that material under stress $S_n = Y_n \epsilon_n$, as defined by Hooke's law of linear ELASTICITY. More generally, Hooke's law of elasticity defines the force ($\vec{F}$) resulting from a spring-type medium or material to be proportional to the linear displacement ($\vec{x}$) while under the influence of the medium, with proportionally constant that is

characteristic of the medium, the spring constant k_{spring} , where the force opposes the displacement as $\vec{F} = -k_{\text{spring}}\vec{x}$ (see Figure H.42).



Figure H.42 Expression of Hooke's law for the jumping motion with a "pogo stick."

Hoop stress (σ_h)

[biomedical, mechanics] A TANGENTIAL STRESS in the WALL of a PIPE (i.e., cylindrical vessel) acting in a cross-sectional plane perpendicular to the longitudinal axis of the pipe $\sigma_h = Pr_i/\delta$, where P is the internal pressure on the wall, δ is the wall thickness, and r_i is the inside radius of the pipe. For thin-walled vessels ($r_i \geq 10\delta$), the forces and stress and strains are derived from the LAME'S EQUATIONS (compare to shear stress) (see Figure H.43).

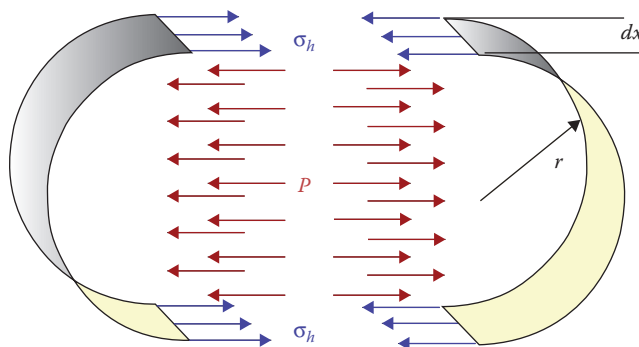


Figure H.43 Diagram illustrating the concept of Hoop stress.

Hormonal signaling

[biomedical, chemical, energy] A glandular secretion of signaling molecules (i.e., hormones) into the BLOOD stream that affects the biological functioning and biological development.

Horsepower (hp)

[general] A measure of power equivalent to watt in the conversion $1 \text{ hp} = 745.699872 \text{ W} = 746 \text{ W}$. The unit horsepower was introduced in 1783 by JAMES WATT (1736–1819) in reference to quantifying the performance of steam engines. The unit was based on the efforts by a draft horse, lifting a 150 pound (~68 kg) object attached to a PULLEY while moving at 2.5 miles/h = 4 km/h, however generously overstated not to discredit the performance of the noble horse as the primary mechanism of work in the day (see [Figure H.44](#)).



Figure H.44 Clydesdale ploughing field.

H-theorem

[energy, nuclear] See **BOLTZMANN'S H-THEOREM**.

Hubble, Edwin Powell (1889–1953)

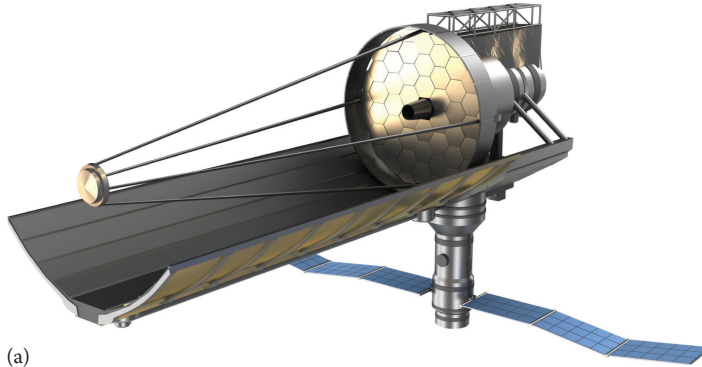
[astronomy] An astronomer from the United States. Edwin Powell is best known for his contributions to the definition of the existence of multiple galaxies in the UNIVERSE. His observation of our neighboring GALAXY, the Andromeda Nebula, led his discoveries to show that the universe is expanding (see [Figure H.45](#)).



Figure H.45 Edwin Powell Hubble (1889–1953).

Hubble space telescope

[general] A SATELLITE equipped with large optical reflective telescope launched in 1990, orbiting the EARTH in GEOSYNCHRONOUS ORBIT. The orbit height is approximately 559 km, providing an unobstructed view of the GALAXY, unhindered by atmospheric disturbances. The Hubble space telescope was notorious for the manufacturing defect and associated failure to check for the quality before sending the TELESCOPE with faulty 2.4 m diameter hyperboloid mirror into space. The MIRROR was not properly polished, generating SPHERICAL ABERRATIONS, distorting the collected data and had to be repaired while in space. The telescope was named in honor of the physicist and astronomer EDWIN POWELL HUBBLE (1889–1953) from the United States. The Hubble space telescope program was initiated in 1977. The telescope is still operational (see [Figure H.46](#)).



(a)



(b)

Figure H.46 (a,b) Hubble Space Telescope.

Hubble's law

[astrophysics, general] A theoretical description of the rate of EXPANSION of the UNIVERSE, defined as $\vec{v} = H_H \vec{r}$, $H_H = 100h^{\text{gal}} \text{ km/sMpc}$, where $\vec{v}$ is the mean recession velocity of the uniformly expanding GALAXY at separation $\vec{r}$, H_H is the Hubble constant, which is undefined at this point due to the inability of placing an absolute value on galactic distances, $0.5 < h^{\text{gal}} < 1$ is a dimensionless constant and length expressed in mega parsecs $1 \text{ Mpc} = 3.08610^{22} \text{ m}$. There is some evidence indicating that the works of both GEORGES HENRI JOSEPH ÉDOUARD LEMAÎTRE (1894–1966) and ALEXANDER ALEXANDROVICH FRIEDMANN (1888–1925) predate the work of EDWIN POWELL HUBBLE (1889–1953).

Hüfner, Carl Gustav von (1840–1908)

[biomedical, chemical] A physiologist, chemist, and scientist from the Prussian Empire (now Germany). Gustav von Hüfner is best known for his description of the chemical ACTIVITY of hemoglobin with respect to oxygen transport in BLOOD in 1866 (see [Figure H.47](#)).



Figure H.47 Gustav von Hüfner. (Courtesy of Hoppe-Seyler's *Zeitschrift für physiologische Chemie*, Vol. 58, November 12, 1908.)

Hüfner's number (*Hü*)

[biomedical] The volume of oxygen that can bind to hemoglobin per gram unit, approximately has a value of 1.34 (technically 1.339), but depends on the boundary conditions. It was determined that 1 g of hemoglobin could maximally bind 0.0598 mmol of oxygen gas, using the molar volume of an IDEAL GAS (22.4 ml/mmol); this provides the scaling parameter 1.339 ml/g, where the MOLECULAR WEIGHT of hemoglobin is 64,458.5. This number is used to determine the oxygen concentration $[\text{O}_2]$ in BLOOD from $[\text{O}_2] = \text{Hü}[\text{Hb}](\text{SaO}_2/100)$, where $[\text{Hb}]$ is the hemoglobin concentration also called hematocrit and SaO_2 is the oxygen saturation, which can be determined by PULSE-OXIMETER measurement among other ways including analytical blood–gas analysis. The blood–oxygen binding analysis was performed by CARL GUSTAV VON HÜFNER (1840–1908).

Hull, Albert Wallace (1880–1966)

[atomic, nuclear] A physicist from the United States. Albert Hull developed the magnetron (as used in MICROWAVE OVEN) in 1921, while working at General Electric. Hull also developed X-RAY crystallography diffraction technique for the structural analysis of powdered crystalline structures. The

diffraction pattern satisfies the BRAGG's EQUATION. Hull developed his experimental design independently from his contemporaries PETRUS (PETER) JOSEPHUS WILHELMUS DEBYE (1884–1966) and PAUL SCHERRER (1890–1969) in 1917. Additional efforts of Hull were in the development of VACUUM tubes (e.g., dynatron and THYRATRON) (see Figure H.48).



Figure H.48 Albert Wallace Hull (1880–1966). (Courtesy of IEEE, New York.)

Human body

[biomedical, chemical, electronics, engineering, materials sciences, mechanics] A biological entity with a broad range of chemical, physical, and mechanical properties. The human body has an internal semi-flexible rigid structure, composed of a skeleton, providing support, equilibrium, and means to apply force, torque, and HOMEOSTASIS. The motions of the body are supported through a system of muscles: smooth muscle, skeletal muscle, and cardiac muscle. The majority of activities, data processing, and data storage are supported by a central nervous system, consisting of the brain and spinal cord and conjunctively a peripheral nervous system. The brain is organized into compartments with specific functions, such as senses (PERCEPTION), MUSCLE control, emotion, next to memory and computation as well as personal behavioral characteristics ("character"). The senses use a variety of PHYSICS and chemistry phenomena as well as mechanical integration. The senses are VISION, HEARING, smell, touch, taste, and pain. The senses are supported through specialized anatomic organs: vision (ophthalmoception) provided by the eyes, hearing (audioception) mediated by the ears, smell (olfacoception or olfacception) a chemical feature of the nose, taste (gustaoception) a chemical interaction with the tongue in the mouth, and touch (tactioception) has a broad range of specialized sensors (including pressure, temperature, and mechanical shear and strain), whereas pain is a stimulus to the brain primarily provided by open-ended nerve endings, but with other sensory extensions as well. The body uses double and triple redundancy for most of its controls and senses and additionally has separated systems that communicate at critical locations for confirmation and amplification as well as response. The physical activities of the human body are regulated by two separate integral systems: central nervous system and peripheral nervous system. The peripheral nervous system contains the autonomic nervous system and the somatic nervous system. The autonomic nervous system is divided into parasympathetic nervous system, sympathetic nervous system, and enteric nervous system, which can operate independently from each other but can also interact with each other. Muscles provide several functions: stability and equilibrium, RESPIRATION next to BLOOD CIRCULATION as the primary source for survival. Smooth muscles are integral to the vascular blood circulation, food and waste transportation, and reproduction. The cardiac muscle is the main pumping mechanism for blood FLOW. The SKELETAL MUSCLE offers a mechanism of force and torque. Movements of the body are carefully regulated by subconscious (autonomic) mechanisms that

provide minimization of effort by means of, for instance, controlling the location of the center of mass during pole jump or increasing the respiratory volume during ACTIVITY. Signal propagation is mediated by nerve cells that use an ACTION POTENTIAL based on a reversible and active (requiring ENERGY to operate) exchange of chemical components. The process of decision making, computing cause and effect and interpretation of data, sensation and relevance to the environmental boundary conditions, and prior history are integrated chemical processes that are still not totally understood. The human body is one of the most in-depth researched topics due to the broad range of resources, but also due to its diversity in parameters. The human body also offers one of the more intriguing challenges for research, continuously seeking novel investigational techniques next to the conundrum of genetic evolution. Examples of investigational topic of interest are the action potential for cellular communications and mechanism of functional activation, next to electrical volume conduction, specifically with respect to the DEPOLARIZATION of the HEART, as well as the FLUID DYNAMICS of the lungs and the blood circulation. Additional fields of ENGINEERING research are in the MECHANICS and control of prosthetic devices, as well as biocompatibility and material durability, including a broad range of quality control aspects. Both diagnostic and therapeutic modalities, including medical device design and development, as well as protection of human subjects (both from the device/mechanism as from the implications of participating in the procedure) are regulated by government institutions such as the Food and Drug Administration (FDA) in the United States, the Medical Device Commission/Council on Medical Devices for the European Union, and the Pharmaceuticals Medical Devices Agency (PMDA) in Japan (see [Figure H.49](#)).



Figure H.49 The human body as a multifaceted, multidisciplinary integration of biology, engineering, physics, electronics, and fluid dynamics.

Human eye

[biomedical, optics] See EYE.

Humidity

[thermodynamics] Water vapor contents in ATMOSPHERE (*also see* ABSOLUTE HUMIDITY *and* RELATIVE HUMIDITY).

Humidity, absolute

[thermodynamics] The physical quantity of water vapor measured in mass as a portion of a unit volume, units (kg/m^3). Absolute HUMIDITY is most often used in METEOROLOGY.

Humidity, relative

[thermodynamics] For water, the ratio of the partial pressure of the VAPOR in a volume of a mixtures of gasses and water vapor with respect to the pressure of the water vapor as a constituent of the mixture (i.e., partial pressure) that will result in condensation due to SATURATION (related term “DEW POINT”) (see [Figure H.50](#)).



Figure H.50 Relative humidity meter: hygrometer.

Hund, Friedrich Hermanns (1896–1997)

[atomic, energy, solid-state, thermodynamics] A German scientist and mathematician dedicating his work to SOLID-STATE PHYSICS. Hund started out as the assistant to MAX BORN (1882–1970) and served with other notable scientists such as ERWIN RUDOLF JOSEF ALEXANDER SCHRÖDINGER (1887–1961), PAUL ADRIEN MAURICE DIRAC (1902–1984), WERNER KARL HEISENBERG (1901–1976), and WALTER WILHELM GEORG BOTHE (1891–1957).

Hund's law

[atomic, energy, solid-state, thermodynamics] See **HUND'S RULE**.

Hund's rule

[atomic, energy, solid-state, thermodynamics] Every orbit in the Bohr's atomic model of electron distribution has single occupation prior to filling the additional paired electron in each respective orbit. These single occupied electron orbits are containing electrons with the electron spins aligned. This formulation was published by FRIEDRICH HERMANN HUND (1896–1997) in 1927. This statement is also referred to as HUND'S LAW.

Huxley, Andrew Fielding, Sir (1917–2012)

[biophysics, chemical, electromagnetism, energy] A physiologist and physicist from Great Britain. Sir Andrew Huxley is best known for his contributions to the description of the formation and propagation of the biological ACTION POTENTIAL as related to the giant squid axon in the early 1940s. The action potential is an electrochemical mechanism that provides a binary communication system. The work was performed in collaboration with SIR ALAN LLOYD HODGKIN (1914–1998) which provided them both with the Nobel Prize in Medicine in 1963. Additionally, their joint efforts provided major insight into the processes involved in muscular contraction, published in 1954 (*also see* HODGKIN–HUXLEY MODEL) (see [Figure H.51](#)).



Figure H.51 Andrew Fielding Huxley (1917–2012) in 2005. (Courtesy of Vmadeira.)

Huygens, Christiaan (1629–1695)

[atomic, general, nuclear, optics] An astronomer, engineer, mathematician, and physicist from the Netherlands. In addition to his work in optics, Huygens contributed to ASTROPHYSICS, MECHANICS (e.g., PENDULUM of a clock), and geometrical mathematics (e.g., definition of the circumference of a circle, revisited for the first time since ARCHIMEDES [287–212 BC] introduced the constant relating radius and circumference as smaller than $3\frac{1}{7}$ and greater than $3\frac{10}{71}$). He is most famous for his pioneering theoretical analysis of the wave phenomenon of ELECTROMAGNETIC RADIATION: the HUYGENS PRINCIPLE, in this context he (re-)introduced the concept of ETHER as a medium through which light propagates (previously conceptually postulated by ARISTOTLE [384–322 BC]). In OPTICS, Huygens introduced the formal description of REFRACTION and double refraction. His work includes a comprehensive outline of LENS characteristics (FOCAL POINT based on curvature: the lens equation) as well as IMAGE formation in 1652. In 1653, Huygens recognized the principle of chromatic and SPHERICAL ABERRATION and gave an elaborate mathematical description of how to account and compensate for these phenomena. He contradicted Newton's principia (1687), which states that all MOTION is absolute by reiterating his postulate that all motion is relative. There is documented proof of the friendship between Christiaan Huygens's father, Constantijn Huygens (1596–1687), with the Dutch painter Rembrandt Harmenszoon van Rijn (1606–1669). Constantijn Huygens is represented in one of Rembrandt's paintings as well (see [Figure H.52](#)).



(a)



(b)

Figure H.52 (a) Christiaan Huygens, (1629–1695) painted by Caspar Netscher (1639–1684). (Courtesy of Collection Museum Boerhaave, Leiden, the Netherlands). Long-term use from the "Haags Historisch Museum," Den Haag, the Netherlands, (b) Constantijn Huygens (1596–1687), painted by Rembrandt van Rijn, in 1627.

Huygens principle

[optics] The concept of WAVE properties for light was introduced by CHRISTIAAN HUYGENS (1629–1695) in 1680 and in his 1690 publication *Traité de la Lumière*. The principle defines that every location in the path of a light beam acts as a spherical source. The superposition principle will result in a PLANE WAVE traveling in the direction of the beam of light, away from the LIGHT SOURCE. This principle becomes of critical importance

when a narrow APERTURE is blocking the path of the light ray, or a solid obstruction, both resulting in diffraction (see [Figure H.53](#)).

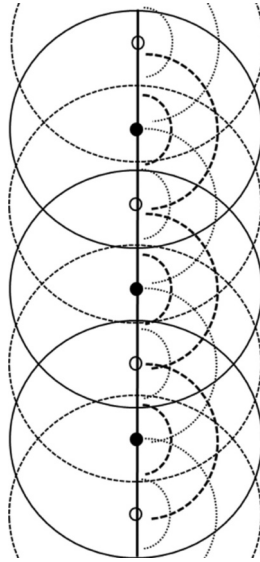


Figure H.53 Illustration of Huygens principle introduced by Christiaan Huygens (1629–1695) for the concept of wave propagation. The same concept is applied in the single slit description under the experimental design of Joseph von Fraunhofer (1787–1826).

Hydraulic impedance

[fluid dynamics] Resistance to FLOW in a tube with cross-sectional area $\mathcal{A}$ is expressed as $Z_b = \sqrt{\rho B_{\text{eff}}} / \mathcal{A}$, with B_{eff} the FLUID COMPRESSIBILITY MODULUS and ρ the DENSITY of the FLUID.

Hydraulics

[fluid dynamics] Having to do with fluids (liquids and gasses) in MOTION or under steady-state conditions interacting with environmental conditions such as confinement in a container. The word comes from the Greek words for water: ὕδρω (hydro) and PIPE: διοχέτευση (diochétefsi: “channeling”) (see [Figure H.54](#)).



Figure H.54 Hydraulic levelers for scooping up soil and rocks.

Hydrogen atom

[atomic, nuclear] The **ATOM** of lightest mass and simplest atomic and nuclear structure, consisting of 1 proton with 1 orbital electron. Its mass is 1.008123 mu.

Hydrogen bomb

[atomic, nuclear] See **H-BOMB** (see [Figure H.55](#)).



Figure H.55 Volumetric expansion under the influence of the heat generated during the explosion of a hydrogen bomb, providing both emission of radiation (heat: infrared, visible, and X-ray as well as beta and gamma radiation), in addition to a pressure wave. Due to the compression of the air outside the volume of atmosphere directly surrounding the explosion, the flow of air will be toward the location of the extinguished explosion directly following the expansion, generating a damped cavitation wave with high Q value ("critically damped").

Hydrogen bond

[atomic, chemical, energy, nuclear] An electrostatic bond between a **HYDROGEN ATOM** and an electronegative **MOLECULE**. The most well-known hydrogen bond is with the diatomic molecule oxygen which becomes electronegative as atomic structure in **WATER**: (H_2O), other examples are hydrogen bonds to nitrogen and fluorine. Water has a strong attraction between the water molecules due to the induced polarity and **DIPOLE** formation with both hydrogen atoms as positive **POLES** and oxygen as the negative pole. In water the hydrogen bond of the induced dipole attracts neighboring dipole oxygen atoms in the H_2O structure. Other examples of hydrogen bonding are in the **DNA** double-helix structure (see [Figure H.56](#)).

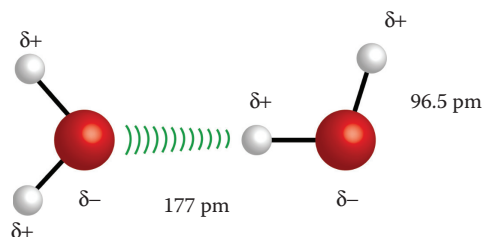


Figure H.56 The effects of the hydrogen bond in water.

Hydrogen spectra

[biomedical, general, imaging, optics] A technique used to map detailed spectral emission profiles as a function of wavelength, based on two-dimensional location. FLUORESCENT and PHOSPHORESCENT LUMINESCENT intensity as a function of wavelength is collected over relatively narrow bands of the ELECTROMAGNETIC SPECTRUM (primarily spanning the visible and infrared), segmented in often hundreds of wavelength ranges. Each segment holds particular information, often overlooked when using standard broadband SPECTROSCOPY. The spectral emission peak are specifically connected to unique ATOMIC structural forces, hence providing MOLECULAR composition details. The critical backdrop to this form of analysis is the existence of a thorough, extensive and detailed look-up table for spectral phenomena (peaks, slope, “groupings,” etc.) to reference against for recognition and identification. For instance in minerals the graphical representation of the SPECTRAL absorption and emission is a direct function of the chemical composition and the crystalline structure, in addition to temperature effects and ambient conditions (dissolved/dry). Specifically the VALENCE of an ELEMENT in a structure can dramatically change the spectral performance on a subnanometer level. The technique was used initially in geographic surface mapping pertaining to oilspills, weather conditions, and agricultural information (e.g., use of herbicides/spectracides/disease localization and optimal growth conditions determination) as examples of REMOTE SENSING. A commercial example is the airborne visible/INFRARED imaging spectrometer (AVIRIS) operated by the NASA Jet propulsion Laboratory. Additionally galactic spectroscopy is used to identify ELEMENTS in the surface construction of remote planes as well as the composition of elements in the incineration flames produced during the NUCLEAR FUSION and FISSION processes on stars. In medical diagnostic endoscopic devices based on FIBER-OPTIC construction (i.e., catheter) are used to graphically localize the configuration of atherosclerotic plaque in arteries, in addition to cervical dysplasia diagnostics to name but a few examples. For the use and history of the units in spectroscopy (see SPECTROSCOPY) (see [Figure H.57](#)).

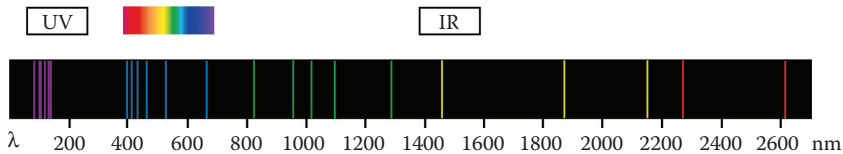


Figure H.57 Hydrogen emission spectrum.

Hydrology

[energy, fluid dynamics, general, geophysics] The field of PHYSICS dealing with physical phenomena in the liquid part of Earth's ATMOSPHERE directly related to the FLOW and PHASE transitions of the oceans and large and small bodies of water.

Hydrostatic paradox

[general] The pressure on the bottom of a closed reservoir filled with LIQUID is independent of the weight of the liquid.

Hygrometer

[energy, fluid dynamics, general, geophysics] A device that measures HUMIDITY. Examples are found in materials that change shape on length in response to the relative number of water vapor molecules in a volume of AIR. One of the oldest and most reliable techniques uses a horses tail hair, which expands and contracts under the influence of water vapor (see [Figure H.58](#)).

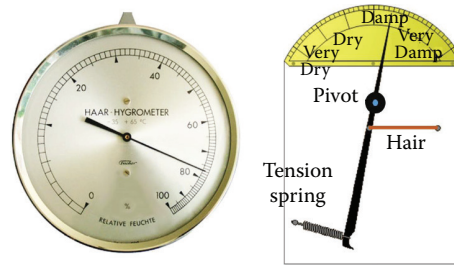


Figure H.58 Hygrometer. (Courtesy of Daniel FR.)

Hyperfine constant

[atomic, energy, nuclear, optics] The constant that describes the split in spectral lines for a specific ELEMENT based on the intrinsic NUCLEAR MAGNETIC MOMENT ($\mu_{I_n} = g_n (m_e/M_n) (e/2mc) \vec{I}$), with g_n the nuclear g -factor, (m/M) the ratio of the electron mass (m_e) over the nuclear mass (M_n), and $\vec{I}$ the nuclear SPIN.

Hyperfine structure

[atomic, energy, nuclear, optics] The emission lines from EXCITED STATES of atomic electron orbits are influenced by both external MAGNETIC FIELD (B) (see FINE STRUCTURE) and NUCLEAR MAGNETIC MOMENT ($\vec{\mu}_n = (Zeg_n/2M_nc) \vec{I}$), with $\vec{I}$ the nuclear spin vector, Z the total number of charges, $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron charge, M_n the nuclear mass, $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of light, and g_n the nuclear g -factor). The orbital electron produces an inherent magnetic field (B_e) which interacts with the nuclear magnetic moment creating a hyperfine structure: $\mathcal{H}_{hf} = a_{hf} \vec{I} \cdot \vec{J}$, where a_{hf} is the HYPERFINE CONSTANT, $\vec{I}$ the nuclear spin, $\vec{J} = \vec{L} + \vec{S}$ the TOTAL ANGULAR MOMENTUM (with total angular momentum quantum number j), combining the ORBITAL ANGULAR MOMENTUM ($\vec{L}$, with orbital angular momentum quantum number ℓ) and

the SPIN angular momentum ($\vec{S}$, with spin QUANTUM number s). The fundamentals of the spectral split came from the work of WILLIS EUGENE LAMB (1913–2008). The hyperfine ENERGY split can be described based on the first-order PERTURBATION THEORY of the interaction of the electron MAGNETIC MOMENT ($\mu_e = (e/mc)\vec{S}$) with the MAGNETIC FIELD $\Delta E = -\mu_e \cdot \vec{B}$, yielding

$$\Delta E = (2/3)(Z\alpha_{hf})^4 (m/M_n)(mc^2)g_n(1/n^3)\left((2/\hbar^2)(\vec{S} \cdot \vec{I})\right) = (2/3)(Z\alpha_{hf})^4 (m/M_n)(mc^2)g_n(1/n^3) \\ \left(j(j+1) - (3/2)\right)$$

(also see ZEEBMAN EFFECT) (SEE FIGURE H.59).

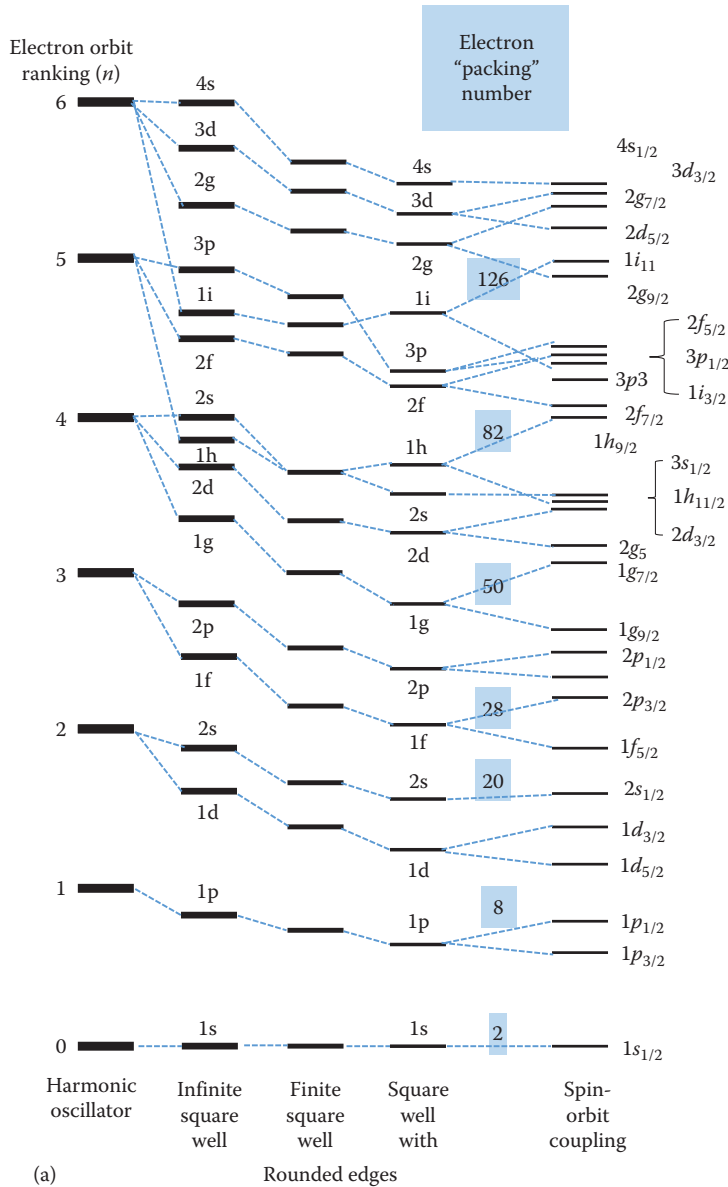


Figure H.59 (a,b) Illustration of the energy split leading to a hyper fine structure, with minute wavelength differences in the emission spectrum. (Continued)

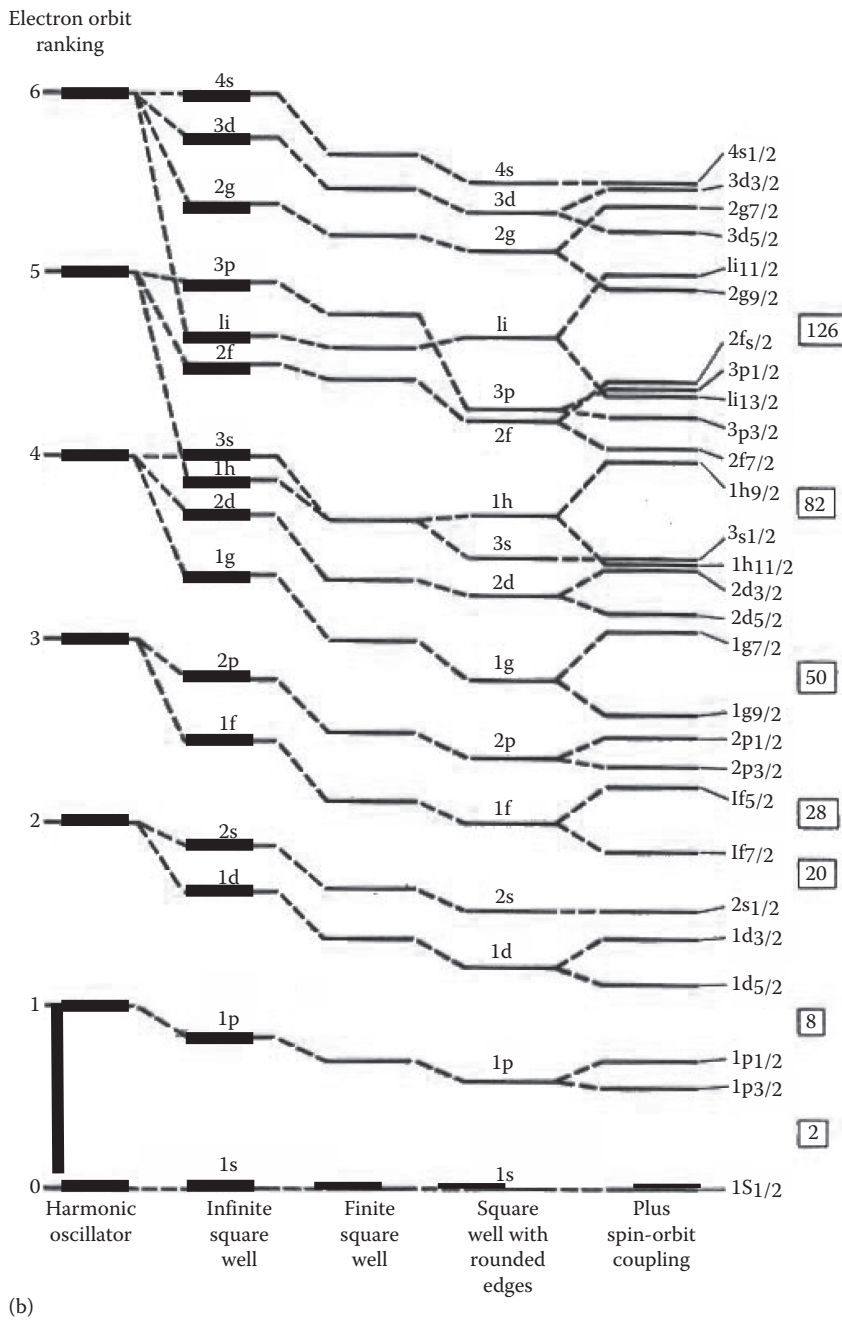


Figure H.59 (Continued) (a,b) Illustration of the energy split leading to a hyper fine structure, with minute wave-length differences in the emission spectrum.

Hypernuclear physics

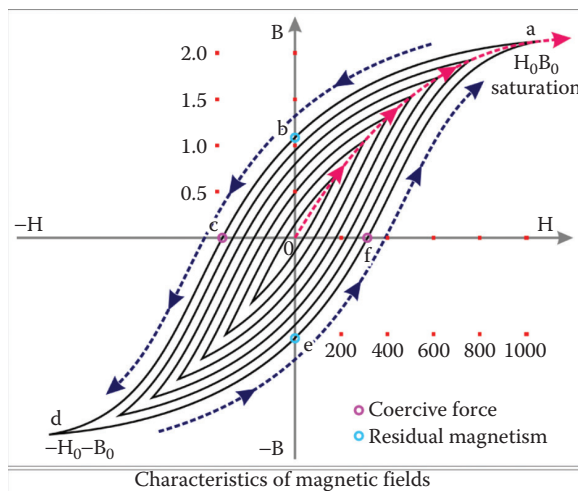
[atomic, general, solid-state] Physical phenomena associated with BARYONS called hyperons, heavier than protons or neutrons. Strangeness is not conserved in hyperon DECAY with lifetimes in the order of 10^{-10} s, in contrast to preservation in strong nuclear interactions.

Hyperspectral

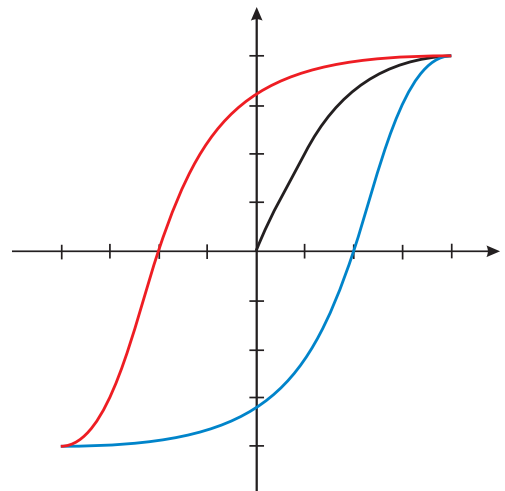
[general, optics] Fine RESOLUTION spectral analysis of a physical process involving the emission or attenuation of ELECTROMAGNETIC RADIATION. Hyperspectral sensing usually references to the combination of the acquisition of an IMAGE or a pattern in electromagnetic detection composed of multiple bandwidth of information, that is, multiple sources or multiple scanning ranges providing a high resolution wavelength decomposition (*also see* SPECTROSCOPY). The spectral decomposition provides the means of discrimination between spectra from sources (e.g., emission/reemission and fluorescence) or components (e.g., attenuation) that are remarkably similar in spectral performance. The process usually involves advanced mathematical processing, primarily using second-order derivative analysis. The multiple spectral scans can be considered to configure an n -dimensional space in the data domain.

Hysteresis

[computational, electronics, electromagnetism, fluid dynamics, mechanics] A phenomenological feature often associated with some form of capacitive effect, which includes a spring. The hysteresis phenomenon applies to mechanical procedures, electrical activities as well as MAGNETIC processes. Under the external influence, a change in mechanical (including fluidic), electrical, or magnetic ENERGY configuration is facilitated with a nonlinear response, often a delay effect; for example, the process appears to try to catch up. The phenomenon describes the condition where the change of state of a system is not accurately reversible under external influences. The change of state in one direction follows a different energy path as the reverse from the final point. The area enclosed by the graph outlining the transition process describes the energy loss per cycle. The most appropriate representation of the hysteresis phenomenon is by means of graphs. In electrical GENERATOR design and the alternating current that is directly associated with the generation of ELECTRICITY, the concept of hysteresis was most important due to the inherent losses associated with it and was recognized as a phenomenon that deserved greater attention by Charles Proteus Steinmetz (1865–1923), a mathematician and electrical engineer from the Prussian Empire (now Poland). The hysteresis provides a major concern for loss when linked multiple generators together, such as found in a wind power “farm” where all the wind generators are out of PHASE and do not turn with the same revolutions (no identical frequencies across the entire field of generators) since the wind velocity and TURBULENCE conditions are different as a function of location in three-dimensional atmospheric volume of flowing AIR (see Figure H.60).



(a)



(b)

Figure H.60 (a,b) Hysteresis, represented by a delay in expression of force resulting from a change in applied magnetic field.

IC (integrated circuit)

[electronics, general] A MICROPROCESSOR chip, SEMICONDUCTOR-layered structure with a specific arrangement of *PN*-JUNCTIONS to accommodate the creation of an ELECTRONIC CIRCUIT resembling RESISTORS, CAPACITORS, OPERATIONAL AMPLIFIERS, and switches as well as digital MEMORY (see Figure I.1).

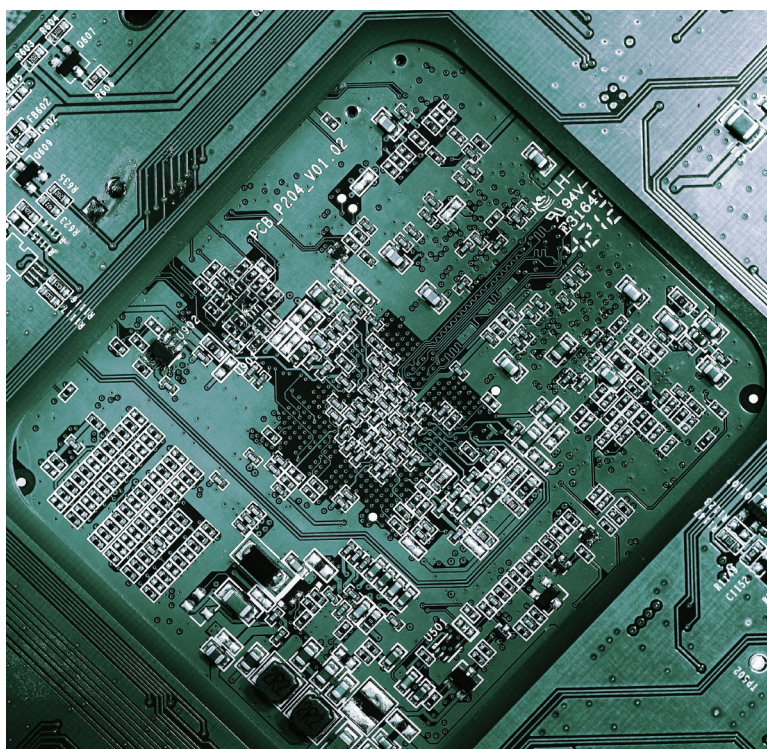


Figure I.1 Microscopic view of printed circuit board of an integrated circuit chip.

Ideal behavior of a mixture

[thermodynamics] An IDEAL GAS MIXTURE is referred to as a GIBBS–DALTON MIXTURE, based on the contributions from JOSIAH WILLARD GIBBS (1839–1903) and JOHN DALTON (1766–1844). The gas is ideal when the PRESSURE (P) is sufficiently low and the TEMPERATURE (T) is high enough to support a VAPOR state of the substances confined in a closed volume. Under these conditions, the INTERMOLECULAR FORCES will be sufficiently weak so that the presence of the molecules of other constituents is relatively

unnoticeable on a force scale. Under these conditions, the individual constituents (total r constituents), with respective amounts: $n_1, n_2, \dots, n_r$ all at equilibrium volume and respective pressure (p_{ii}) with the respective internal energy (u_{ii}) and entropy (s_{ii}), yield for the energy (U) and ENTROPY (S) of the system: $U(T, P, n) = \sum_{i=1}^r n_i u_{ii}(T, p_{ii})$, respectively, $S(T, P, n) = \sum_{i=1}^r n_i s_{ii}(T, p_{ii})$, that is, the sum of the conditions for the components in the volume. Inherent to these conditions is the fact that the total pressure is the sum of the partial pressures for the constituents, defined by the DALTON LAW OF PARTIAL PRESSURES: $P = \sum_{i=1}^r p_{ii}(T, p_{ii}, y)$, where $y = n_i/n = (x_i/M_i) / \sum_{j=1}^r (x_j/M_j)$: $y_1, y_2, \dots, y_r$, represent the MOLE fractions of the constituents, with $M = m/n$ the MOLECULAR WEIGHT of the mixture with mass m and x_i the respective mass fractions.

Ideal behavior of a substance

[thermodynamics] Apart from ideal gases, there are solids and liquids to consider as well, each with the respective conditions define an ideal substance. For solids and liquids, the equilibrium enthalpy between the constituents, under conditions of PRESSURE (P , respectively, the specific pressure: p) and TEMPERATURE (T) and VOLUME (V) constraints, is one of the factors that delineates the IDEAL INCOMPRESSIBLE BEHAVIOR. Ideal incompressible behavior is defined by the SPECIFIC HEAT ($c_v = du/dT$) and internal energy (U , respectively, the specific internal energy: u) as well as the entropy (S , respectively, the specific entropy: s), using the coefficient of isobaric EXPANSION: $\alpha_p = (1/v_m)(dv_m/dT)_p$, with $v_m = m/V$ the mass-specific volume, m the mass of the constituent: $du = c_v dT + [(\alpha_p T / \kappa_T) - p] \cong c_v dT$, with $\kappa_T = -(1/v_m)(dv_m/dP)_T$ the coefficient of isothermal compressibility; $ds = (c_v/T) dT + (\alpha_p / \kappa_T) dv_m \cong (c_v/T) dT$; and respectively the ideal approximation for the enthalpy (H , respectively, the specific enthalpy: h): $dh = T ds + v_m dp \cong c_v dT + v_m dp$. Additionally, the chemical potential will be consistent for all constituents; see CHEMICAL POTENTIAL and FUGACITY. This defines the ideal substance in general, LIQUID, solid, or GAS.

Ideal fluids

[fluid dynamics, general] See IDEAL BEHAVIOR OF A SUBSTANCE.

Ideal gas

[fluid dynamics, thermodynamics] A FLUID mixture with constituents that are far enough apart that the internal ENERGY is not affected by the proximity of other molecules. Generally, a diluted gas, with conditions that are far from SATURATION conditions.

Ideal gas law

[general] The PRESSURE (P) and VOLUME (V) of a GAS are inherently connected through the number of molecules of the gas (moles of substance: n) and the temperature, expressed as $PV = nRT = Nk_B T$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant, which is linked to the AVOGADRO'S NUMBER ($N_A = 6.022137 \times 10^{23} \text{ J/K}$) through the BOLTZMANN CONSTANT ($k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$) as $k_B = R/N_A$, and N represents the number of molecules of gas. The ideal gas law is derived from the experimental observations performed by ROBERT BOYLE (1627–1691) and JACQUES ALEXANDRE CÉSAR CHARLES (1746–1823). In 1662, Robert Boyle recognized that a fixed quantity of gas at constant temperature hold a fixed relation between pressure and volume $P_1 V_1 = P_2 V_2$, while Jacques Charles in 1787

discovered the relationship between volume and temperature (in KELVIN) under constant pressure as $V = \text{Const} \times T$. Further contributions by JOSEPH LOUIS GAY-LUSSAC (1778–1850) in 1802 showed that the pressure of a gas is directly proportional to its temperature $P/T = \text{Const}$. The ideal gas law is a property under the EQUATIONS OF STATE for a medium. The ideal gas law is often referred to as the BOYLE–GAY-LUSSAC LAW (see Figure I.2).

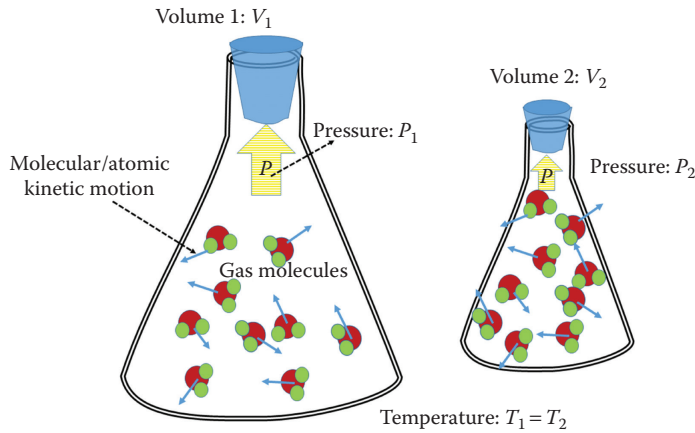


Figure I.2 Ideal gas law conditions.

Ideal gas mixture

[thermodynamics] See IDEAL BEHAVIOR OF A SUBSTANCE and IDEAL SOLUTION.

Ideal incompressible behavior

[thermodynamics] See IDEAL BEHAVIOR OF A SUBSTANCE.

Ideal solution

[thermodynamics] A SOLUTION is defined as a mixture of two components, for which one constituent has a greater quantity than the other and the prevailing component of the AGGREGATION is the SOLVENT and the minority constituent the SOLUTE. The solvent will be in LIQUID form where the solution is considered dilute when the molar fraction of any of the respective solutes is significantly smaller than the MOLE fraction of the solvent. Under conditions of dilution, a weak solution provides the conditions that the nearest neighbors to any respective solute MOLECULE are primarily solvent molecules. The CHEMICAL POTENTIAL ($\mu_i = (\partial G / \partial N_i)_{T, P, N_{j \neq i}}$), also known as the partial molar ENERGY, where G represents the Gibbs free energy, and N_i represents the particulates for the respective constituents, under the operational conditions (concentration [ION], pressure [P], and temperature [T]) for a dilute solution provided as $\mu_i = \mu_{i0}(T, P) + RT \ln y_i$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal GAS constant, and $y = n_i/n = (x_i/M_i) / \sum_{j=1}^r (x_j/M_j)$ represent the mole fraction for the respective constituents. In the composition, the following notation is introduced: $\square_i = y_i$ Parameter, for the i th constituent.

This yields for the enthalpy $h_i = h_{ii}(T, P_i)$, $H(T, P_i, n_1, n_2, \dots, n_r) = \sum_{i=1}^r n_i h_{ii}(T, P_i)$; respectively, for the entropy for a system for r constituents: $S(T, P_i, n_1, n_2, \dots, n_r) = \sum_{i=1}^r n_i s_{ii}(T, P_i) - R \sum_{i=1}^r n_i \ln y_i$; for the internal energy: $u_i = u_{ii}(T, P_i)$, $U(T, P_i, n_1, n_2, \dots, n_r) = \sum_{i=1}^r n_i u_{ii}(T, P_i)$; the respective partial volume: $V(T, P_i, n_1, n_2, \dots, n_r) = \sum_{i=1}^r n_i v_{ii}(T, P_i)$, with $v_m = m/V$ the mass-specific volume.

Ideal voltage source

[electronics] Voltage source with zero internal RESISTANCE (*also see* ELECTROMOTIVE FORCE).

Identical particles

[atomic] Atomic, nuclear, and SUBATOMIC PARTICLES are considered to be identical under conditions of identical mass, identical half-integral intrinsic SPIN (for fermions), identical integral intrinsic spin (for bosons), and identical charge.

Identical states

[thermodynamics] A system with multiple constituents with respective values of the parameters for constituents that are all identical as well as the respective magnitudes of all the properties for each respective state are identical between all states of the components for the system. In case any of the values and properties are different from each other, the states are considered to be different.

Identical systems

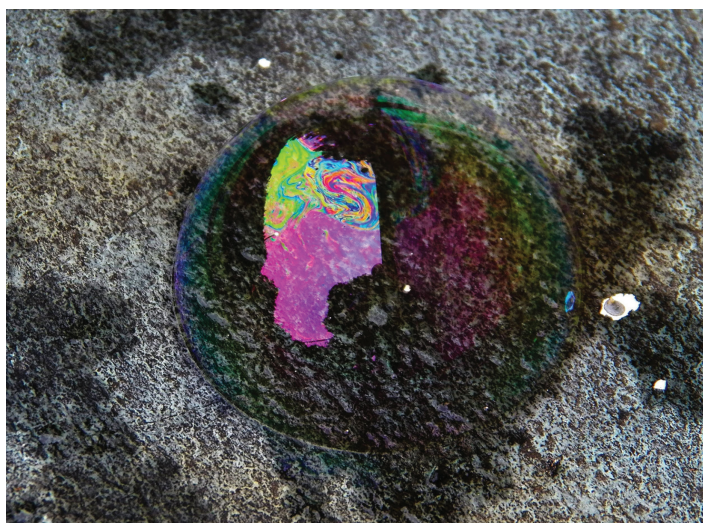
[thermodynamics] Two or more systems are considered to be identical if they are experiencing the same forces, are composed of the exact same constituents in the same quantities, and have the same parameters for entropy and pressure, volume, and so on and operate under the same constraints.

Image

[acoustics, biomedical, fluid dynamics, imaging, quantum] The definition of an IMAGE is a two- or three-dimensional array of datapoints, in contrast to a one-dimensional single observation. Images are acquired by various technological means, ranging from optical techniques using OPTICAL COHERENCE TOMOGRAPHY to regular microscopy, next to the following examples of a wide array of imaging technology and imaging ENGINEERING features: POSITRON EMISSION TOMOGRAPHY, X-RAY, MAGNETIC RESONANCE IMAGING (MRI), ELECTRON MICROSCOPY, helium-ion microscopy, ULTRASOUND, and general PHOTOGRAPHY. Images can be analyzed for content and feature extraction, such as functional aspects based on TRACERS in fMRI or based on time- and frequency-dependent encoding in pulse oximetry. A wide range of spectral imaging techniques are available to reveal signature-based features of components and events, such as “RED-SHIFT” or “BLUE-SHIFT” with respect to DOPPLER modified acquired SIGNAL due to relative MOTION. The graphical representation of data in a diagram or plot may also be considered an image under certain circumstances. In particular, diagrams containing detailed information about a process or a phenomenon are an image formation of the feature, for instance, the Raman spectral profile represents the chemical, energetic, and structural information on a molecular scale, which cannot be imaged directly (see Figure I.3).



(a)



(b)

Figure I.3 (a) Image of a sail boat on a river, providing two-dimensional information about the location of the shore with respect to the boat, in addition to virtual three-dimensional information about the extent of the channel, next to information about the weather conditions, direction of the wind based on the orientation of the flag and relative humidity of the air (no fog), as well as additional information about the materials may be derived and (b) image presenting the spectral profile of a soap bubble. In pollution control, the disposal of waste oil on open waters by ships can be tracked by spectral analysis of the oil-slick floating on top of the water in the ocean. The oils sold in many harbors for lubrication purposes is generally mixed with agents that can be traced based on the spectral signature, acquired by patrolling monitoring planes. Hence, the polluters may potentially be identified.

Imhotep (approx. 2725 BC)

[biomedical, general] The first recorded analytical physician as well as priest from Egypt. Documented as routinely using analytical processes for diagnostic and derivation of cause of an ailment and the most logical cause of action for the most effective treatment based on the available information and the available treatment options in the day (see [Figure I.4](#)).



Figure I.4 Engraved teachings of the Egyptian “high-priest” of medicine, Imhotep (approx. 2725 BC), and illustrations of a selection of medical instruments.

Immiscible substances

[thermodynamics] Two substances are considered to be miscible under the condition that they are mixed in any proportion and they will always form a single liquid PHASE, for instance, ALCOHOL and water (limited boundary conditions). In contrast, two substances are considered to be immiscible under the condition that when mixed in any proportion they will always form two separate phases, for instance, under LIQUID form water and mercury.

Immunoglobulin superfamily

[biomedical, chemical] In biology, there is cell-to-cell binding and communication interaction that can be divided into four types of receptors: CADHERINS, selectins, INTEGRINS, and immunoglobulin superfamily. The immunoglobulin superfamily has a molecular structure that is similar to immunoglobulins. Examples of the immunoglobulin superfamily are found in intracellular connective molecular chains and for neural CELL molecular binding.

Impedance (Z)

[acoustics, electronics, general] An expression of the complex relationship between two phenomena based on the combined effects of RESISTANCE, inductance, “recoil,” and capacitance (i.e., partial energetic storage). Both for acoustic WAVE propagation and electronic wave propagation, there are a set of independent material properties that combine to form the impedance for the system. In ACOUSTICS, the mechanical impedance is the primary factor that determines the conditions in IMAGE formation for ULTRASONIC IMAGING as in the determination of flaws (gradients) or failure (discontinuity) based on the definition $Z = \vec{F}(\lambda)/\vec{v}(\lambda)$, where $\vec{F}$ represents the local force, $\vec{v}$ the velocity vector, and λ the wavelength of the phenomenon (ultrasound FREQUENCY ($\nu = \nu_s(r)/\lambda$, where $\nu_s(r)$ the location-specific speed of SOUND), which can be linked to the ELASTIC MODULUS (E_Y) for a MASS (m) distribution over a volume of medium (V) as $Z = \sqrt{E_Y(m/V)}$. Alternatively, in ELECTRONICS the impedance is the combined effect provided by the series in parallel configuration of electronic components with base features resistance (R , SCALAR); inductance ($X_L = \omega L$, referred to as the inductive reactance, with $\omega = 2\pi\nu$ the ANGULAR FREQUENCY of the alternating phenomenon; complex vector value) and capacitance ($X_C = 1/\omega C$, referred to as the capacitive reactance; complex vector value). The total impedance is the combined effect of the residual components expressed as $Z = \sqrt{R^2 + (X_L - X_C)^2}$ (see Figure I.5).

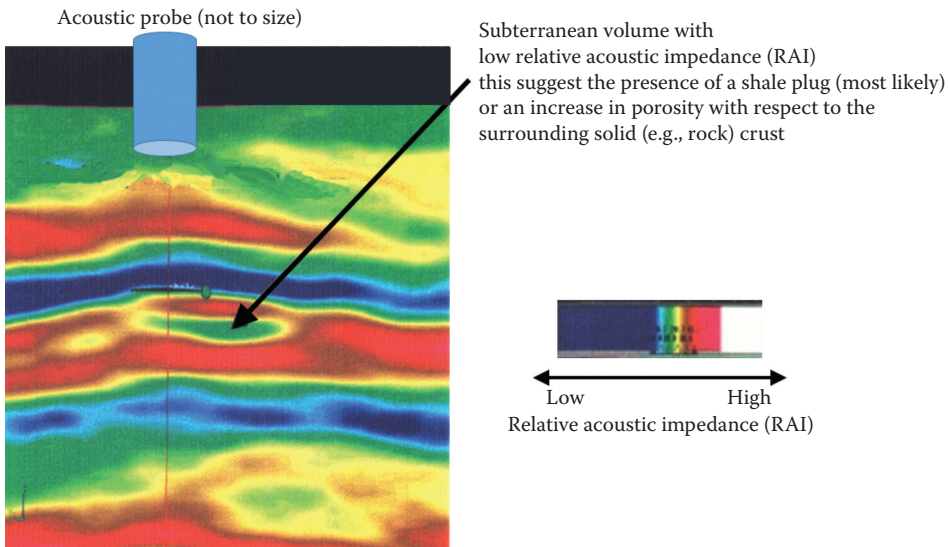


Figure I.5 False-color illustration of the acoustical impedance as a function of depth for the earth's crust in a single location with respect to the identification of risk assessment in seismic features and seismic potentials. (Courtesy AAPG datapage. Online journal for E&P Geoscientists. <http://www.searchanddiscovery.com/documents/2005/strecker/images/03.html>.)

Impedance spectroscopy

[biomedical, electronics, imaging] An imaging technique that collects the FREQUENCY SPECTRUM as a function of location, derived from line-intersect value reconstruction. The fact that the impedance is a function of frequency of electronic perturbation provides a mechanism of action for discrimination of media or conditions of media based on location. The frequency DISPERSION as well as PHASE delays introduced by gradual transitions or respectively boundaries creates discontinuities that result in partial or full reflection as well as DOPPLER shifts and phase modulations that can be retraced and used to form a virtual IMAGE of the electronic properties. The electronic properties are inherently linked to the material phase, the biological ACTIVITY, or the local temperature and can be retraced to the physical composition and functional analysis based on look-up tables and theoretical analysis. The theoretical analysis uses the parallels between ELECTRONICS and SOLID-STATE values, respectively, as biological activity

and the measured frequency response. Electrochemical impedance spectroscopy provides the tools for characterization of electrochemical systems. The applications of impedance spectroscopy are of particular importance in the characterization of materials. Impedance spectroscopy applications range from characterization of coatings, quality control on batteries and fuel cells, as well as in nondestructive testing applied, for instance, to corrosion phenomena. It also provides investigational mechanism for the quality, composition, and density distribution of constituents in electrodeposition, electrodisolution, passivity, and corrosion studies, next to the investigation of biosensors and semiconductor interfaces (see Figure I.6).

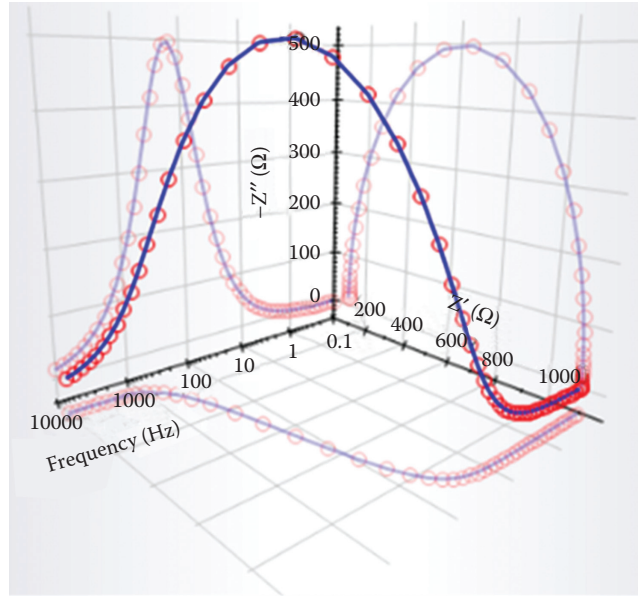


Figure I.6 Impedance spectroscopic recording.

Implicit approximate factorization method

[fluid dynamics] A mathematical algorithm used to analytically solve steady-state FLOW under transonic conditions. The implicit need for the development of an appropriate approximation is the fact that this type of problem generally requires a finite ELEMENT approach. The computational FLUID DYNAMICS approach is required due to the fact that the conditions involve mixed elliptic–hyperbolic functions. The implementation of the implicit approximate factorization method involves the introduction of a small perturbation to the potential (ϕ) equations, for instance, as $\left[k - (d\phi/dx) \right] (d^2\phi/dx^2) + (d^2\phi/dy^2) = 0$, which in turn suggest the introduction of a recursive series for substitution in the analog solution process, for instance, defined as $(d^2\phi/dx^2)^{n+1} + (d^2\phi/dy^2)^{n+1} = \left[\ell + (d\phi/dx)^n - k \right] (d^2\phi/dx^2)^n$, where k and ℓ are functional constant derived from the discrete Laplacian used to solve matrix equations.

Impulse ($\vec{J}$)

[general, mechanics] The rate of change in MOMENTUM ($\vec{p}$) accumulated over a period of TIME (t) equals the accumulated net applied force ($\vec{F}$) during that same interval, expressed as $\vec{J} = \int_0^t (\vec{dp}/dt) dt = \vec{p}_1 - \vec{p}_0 = \int_0^t \vec{F} dt$. The impulse is primarily of importance when a force is applied over a short period of time, and during this brief moment, the force can be relatively large, such as a hammer hitting a nail. However, in most short-duration events, the momentum is a more useful concept. Alternatively, the applied force is the rate of change in impulse (see Figure I.7).



Figure 1.7 Impulse used in practical applications: (a) impulse from a hammer and (b) impulse from a pneumatic nail-gun.

Impulse noise

[biomedical, electronics, thermodynamics] Noise in SIGNAL detection due to faulty ELECTRONICS. This stands in contrast to GAUSSIAN NOISE, which is more indicative of thermal NOISE in the operations of the electronics.

Impulse response

[acoustics, electromagnetism, general, optics, theoretical] The spatial and frequency response of a system with respect to a delta function excitation process. Generally, the spatial response will widen the field due to DISPERSION and diffraction properties; additionally, the FREQUENCY SPECTRUM can be altered in wavelength-SPECIFIC WEIGHT as well as providing specific RESONANCE frequencies where the response is more intense. The output is coupled to the input for the impulse response through the transfer function. The impulse can be a delta function with respect to location or with respect to time; otherwise, the impulse may be a line or a cross, for a two-dimensional line source. The response is generally referred to as the point-spread function. The impulse response can be originating in the excited medium or can be a property of the sensor device and instrumentation acquiring the responses in the medium that is probed by the impulse. In the frequency domain, the response is referred to as the modulation transfer function, denoting the FOURIER TRANSFORM of the point-spread function when considering the spatial information as a discrete distribution of secondary sources separated by intervals, defining a spatial frequency. The “IMAGE” ($i(x', y')$) formed is defined by the convolution ($\otimes$) of the source or “object” ($o(x, y)$) and the respective point-spread function ($b(x, y)$) as $i(x', y') = o(x, y) \otimes b(x, y)$, which is applied directly to lens use in OPTICS. In optics, the focal DISTANCE of the LENS forms the foundation for the point-spread function, with additional details provided by the RAYLEIGH CRITERION. In the Fourier domain, the impulse

response is defined as the cross product of the Fourier transform of the input signal ($O(\xi, \eta)$) and the modulation transfer function ($H(\xi, \eta)$), which yields the “image” ($I(\xi', \eta')$) defined as $I(\xi', \eta') = H(\xi, \eta) \times O(\xi, \eta)$ (see Figure I.8).

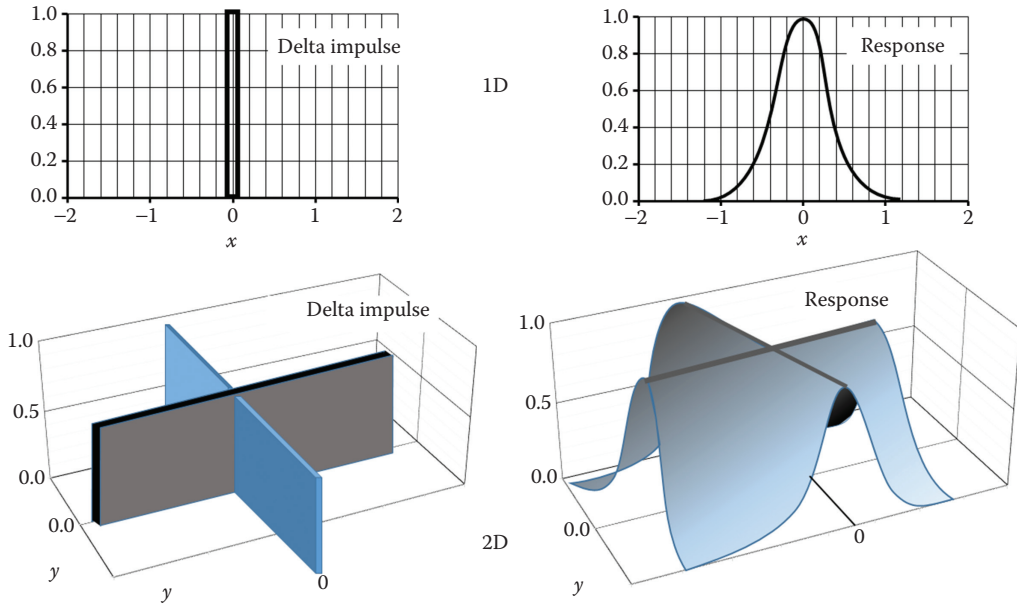


Figure I.8 Graphical illustration of an impulse response for a system.

Incompressible fluid

[fluid dynamics, thermodynamics] Fluid (liquid or gas) that will not change density under applied external pressure.

Increasing criticality

[nuclear] The term “criticality” refers to the NEUTRON balance in a nuclear reaction for a nuclear power plant. A system is subcritical when the loss of neutrons, generated by the FISSION process, resulting from the implementation of a MODERATOR is larger than the generation of new neutrons. Gradual removal of the moderator will result in an increasing criticality, generally targeting a perfect balance between neutron production and neutron quenching. The rate of increase should adhere to specific safety boundaries.

Indeterminacy principle

[atomic, nuclear] Also see UNCERTAINTY PRINCIPLE.

Index of refraction (n)

[general] Optical density of a medium expressed as the ratio of the speed of light in VACUUM ($c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s) divided by the local speed of light in the medium (v): $n = c/v$ (see Figure I.9).

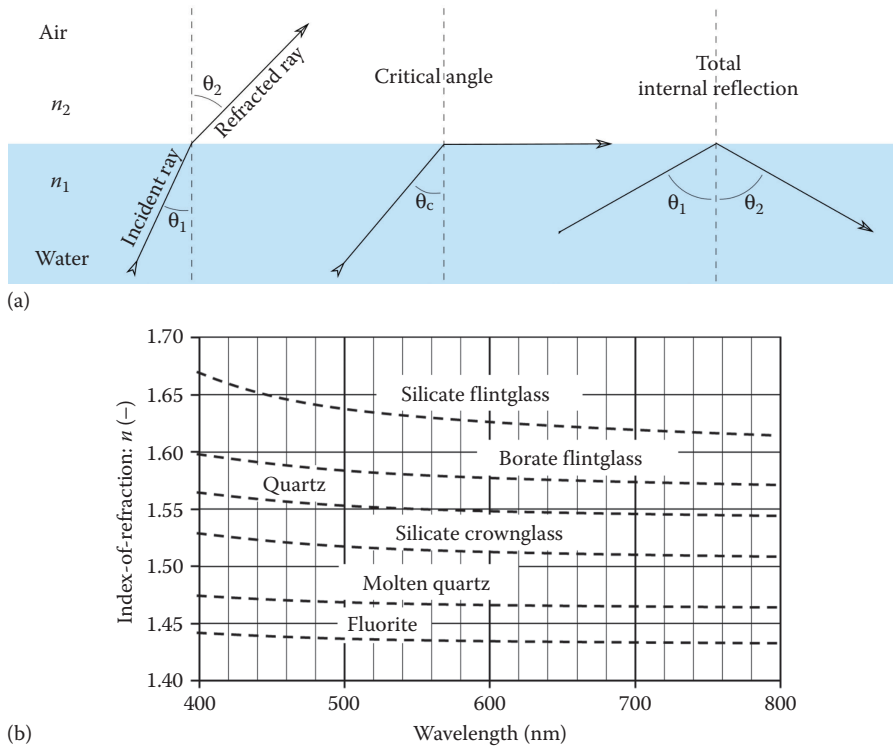


Figure I.9 (a) Illustration of the redirection of the path of a ray under a discontinuity of the index of refraction at the interface between two media. The velocity of propagation in medium 2 is less than medium 1, causing the Poynting vector to redirect, resulting in diffraction and (b) the index of refraction of certain media as a function of wavelength.

Induced emf (electromotive force)

[general] Electrical potential created as a result of changes in the electric and or magnetic fields with respect to a wire loop. For an **INDUCTOR**, this is described as $\epsilon_{\text{emf}} = -L(dI/dt)$, with L representing the inductance for the wire loop and I the current generating the **MAGNETIC FIELD**. This translates for a wire loop with N -windings into $\epsilon_{\text{emf}} = -N(d\phi_B/dt)$, where $\phi_B = BA \cos \theta$ indicates the magnetic flux of the perpendicular component of a magnetic field (B) through a loop with area A . In case the **ANGLE** changes over time, the magnetic field piercing the area will inherently change in **MAGNITUDE**, as found for the rotating wire loop of a **GENERATOR** (also see **FARADAY'S INDUCTION LAW**) (see Figure I.10).

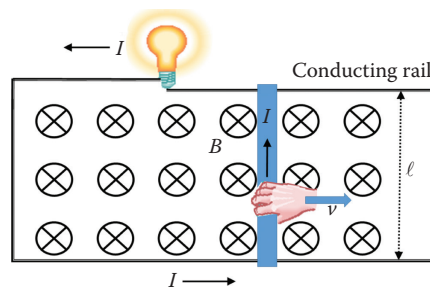


Figure I.10 Induced EMF generation process.

Inductance (L)

[electronics, general] The property of a coil of wire with a CURRENT (I) passing through to generate an electromotive force in its own circuit based on the produced MAGNETIC FIELD (B) with magnetic flux $\Phi_B = BA$ through the area of the coil (A) with N winding expressed as $N\Phi_B = LI$, which provides $L = \mu_0 N^2 A / l$, where $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$ is the permeability of free space. Inductance is used in transformers to reduce or increase the electrical potential by means of linking two loops with a different number of windings, channeling the magnetic field through a metallic portal. Inductive heating is one of the several ways through which heat is produced to facilitate stovetop cooking, resulting from ENERGY conversion based on the fact that the induction process by choice is not ideal. Inductive heating requires special equipment, whereas conduction or convection heating primarily requires a material that conducts heat.

Induction motor

[electromagnetism, general, mechanics] A rotational device that relies on the interaction of a changing magnetic field with respect to a current loop, either the MAGNETIC FIELD changes due to a changing current in a wire loop, with a steady-state current loop (DC) placed within the magnetic field gradient, or alternatively the current changes as a function of time while placed in a steady-state magnetic field. The force that results from this interaction produces a torque that provides the means for rotation when one of the loop systems is mounted on an axle that is centered in the outside mechanism. The torque is defined as a function of the magnetic field vector ($\vec{B}$) in relation to the current $\tau = \vec{\mu}_m \times \vec{B}$, where $\mu_m = NIA$ is the magnetic moment for a CURRENT (I) loop with N winding with a cross-sectional area A . This is derived from the fact that the force on a wire with length ℓ conducting a current I exposed to a magnetic field under ANGLE θ is $F_B = \ell \vec{I} \times \vec{B} = \ell |\vec{I}| |\vec{B}| \sin \theta$. The induction concept was researched extensively by NIKOLA TESLA (1856–1943) (see [Figure I.11](#)).

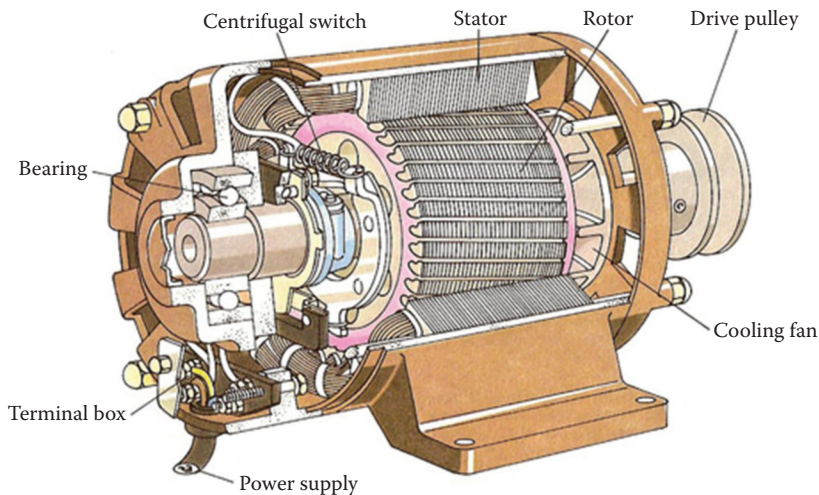


Figure I.11 Outline of an induction motor.

Inductive reactance (X_L)

[general] The complex definition with respect to the temporal response of a coil with inductance L is $X_L = \omega L$, where $\omega = 2\pi\nu$ is the ANGULAR FREQUENCY of the temporally changing phenomenon, operating at a frequency ν .

Inductor

[general] A wire loop that produces a MAGNETIC FIELD that attempts to counteract the magnetic field produced by the current flowing through the wire in the multiple loops, referred to as SELF-INDUCTANCE. Alternatively, the inductor is a wire loop that generates an electromotive force (electrical potential) that is the result of the changing magnetic field through the wire loop (see [Figure I.12](#)).

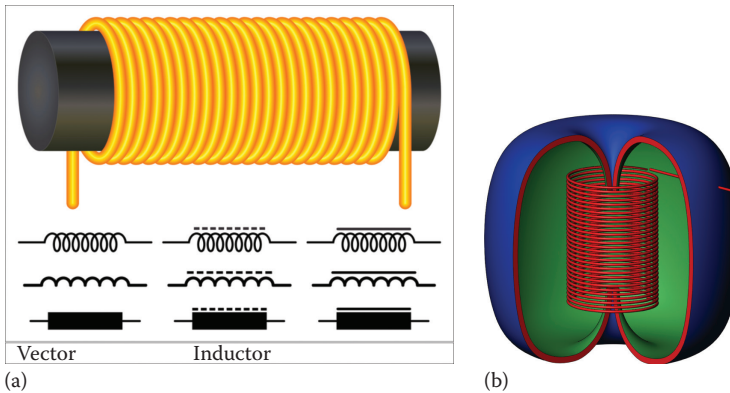


Figure I.12 (a,b) Diagram of a wire-loop inductor.

Inelastic collisions

[biomedical, general, mechanics] Collision where some ENERGY is converted from kinetic to other forms of energy, sometime deformation, sometimes heat, or may result in conversion from a portion of translational energy into rotational energy (see [Figure I.13](#)).



Figure I.13 Example of a totally inelastic collision. All kinetic energy has been converted in deformation energy.

Inelastic scattering

[nuclear] See CROSS SECTION *and* NUCLEAR REACTION.

Inertia

[general] General unwillingness to change motion; an object in MOTION will remain in motion when there are no external forces acting (which includes the absence of FRICTION and/or AIR DRAG), recognized as such by SIR ISAAC NEWTON (1642–1727) (see [Figure I.14](#)).



Figure I.14 Example of almost frictionless motion for a bobsled (bobsleigh). The initial kinetic energy supplied while running for take-off can sustain a constant velocity for a considerable time on a level surface. The conversion of potential energy to kinetic energy during down-hill slide is not impulse, but is converted into impulse.

Inertia, moment of (*I*)

[general] See MOMENT OF INERTIA.

Inertial reference frame

[general, mechanics] A reference frame in which NEWTON'S FIRST LAW is validated. For example, a reference frame relative to the first fixed STAR is inertial, specifically the velocity of the Sun in our SOLAR SYSTEM does not vary more than 10^{-10} with respect to other stars. The earth's movement with respect to the sun's inertial frame is technically not inertial since, due to the rotation and revolution trajectory around the Sun, there is acceleration involved; however in most cases, the deviation can be neglected ($< 3.4 \times 10^{-2} \text{ m/s}^2$) and reference frames attached to the earth's surface are considered inertial (by approximation) (see [Figure I.15](#)).



(a)

Figure I.15 Inertial reference frame on the moving sailboat (a) with the reference frame with respect to a plane in motion. (Continued)



(b)

Figure I.15 (Continued) (b) Inertial reference frame on the moving sailboat in the land-based frame of reference.

Infinite square well

[atomic] See POTENTIAL WELL.

Infrared

[general, optics] A spectrum of ELECTROMAGNETIC RADIATION beyond the visible red, starting approximately at a wavelength of 660 nm, extending to the MICROWAVE range of 1 mm, discovered in 1800. Infrared pictures reveal thermal vibrations of ELECTRIC CHARGES, yielding the temperature profile of an object with respect to background (see [Figure I.16](#)).



Figure I.16 Image showing the infrared radiation emitted from a heated house, with special attention to surface areas that have a lower insulation value with respect to other areas, such as the windows.

Infrared electromagnetic radiation

[general, optics] See **INFRARED**.

Infrared spectroscopy

[imaging, optics] See **SPECTROSCOPY**.

Infrasound

[acoustics, general] **ACOUSTIC WAVES** with frequencies below the audible range, below the cut-off frequency of 20 Hz, and wavelength in **AIR** exceeding 17.2 m in air, respectively.

Ingenhousz, Jan (Ingen-Housz or Ingen Housz) (1730–1779)

[biomedical, geophysics, thermodynamics] A medical doctor, physiologist, chemist, and scientist from the Netherlands attributed with describing the concept of **PHOTOSYNTHESIS**. As a physician, he was an avid supporter of inoculation and disease prevention (see [Figure I.17](#)).



Figure I.17 Jan IngenHousz (1730–1779).

Inner ear

[biomedical, general] The cochlea of the **EAR** that contains the transfer mechanism from wave **MECHANICS** to binary electric **SIGNAL** by the **ORGAN OF CORTI** for transmission to the brain with subsequent processing. The inner ear is connected to the **MIDDLE EAR** by means of the oval window, sealing off the liquid-filled cochlea from the middle ear that is connected to the outside **AIR** via the **EUSTACHIAN TUBE**. The inner ear is liquid filled with two distinct types of liquids that conduct the **ACOUSTIC WAVES**, referred to as the perilymph and the endolymph. The cochlea is shaped in the form of a snail-shell labyrinth with two canals. The sensory cells are located in the **BASILAR MEMBRANE** of the labyrinth located in the vestibular system, which have a frequency response that is location (r , primarily a linear function of the **DISTANCE** into the cochlear loops only) specific. The location-specific frequency response is as follows, with the sensor cells at the beginning, close to the oval

window sensitive to high frequencies (~ 20 kHz down) while the lowest audible frequencies in the 20 Hz range are toward the opposite and far end. The frequency response is anatomically configured to be optimal based on the local resonance conditions (ω_0), hence providing a high degree of acuity and narrow frequency bandwidth as a function of location. The FREQUENCY ($\omega = 2\pi\nu$, where ω is the ANGULAR FREQUENCY and ν the actual temporal frequency) response of the basilar membrane in the cochlea can be modeled as a frequency-dependent ACOUSTIC IMPEDANCE (Z) defined by the stiffness of the local segment of the partition ($K_{\text{basilar membrane}}(r)$), a location specific dampening factor ($D(r)$) has been found to obey a function defined as $Z(r, \omega) = 1/A^2(r) \sqrt{\{M(r)\omega_0 - [K_{\text{basilar membrane}}(r)/\omega_0]\}^2 + D^2(r)}$, where $A(r)$ is the local cross-sectional area at a specific location in the cochlea and $M(r)$ the mass at a specific location of the cochlear partition. The acoustic impedance is a parameter linking the local pressure ($P_d(r, \omega)$), during pressure perturbation) to the displacement velocity of the local media ($v_d(r, \omega)$) as $v_d(r, \omega) = Z(r, \omega)P_d(r, \omega)$, respectively expressed in terms of ACOUSTIC INTENSITY (I_a) as $I_a(r, \omega) = P_d^2(r, \omega)/Z(r, \omega)$, hence creating the ideal RESONANCE in a specific location for the appropriate frequency (i.e., an acoustic filter), exciting only those sensors designed to record a specific frequency, which is subsequently conveyed to the brain for signal processing, convolution, and interpretation. The acoustic impedance also results in phase delays and DISPERSION effects that are compensated for in the integral structure of the inner ear. The WAVE traverses the vestibule, once inward via the utricle half of the vestibule and on return through the saccule, where the SOUND traverses the path of the looped bony labyrinth outlining the cochlea, which consists of $2(2/3)$ turns. The conversion (and associated transfer function) for the displacement of the endolymph FLUID in mechanical MOTION takes place by special cells in the ORGAN OF CORTI that are stretched by the LIQUID displacement. The stretch of these “hair-cells” appears, where the hairs wave as the underwater kelp of the beach shore on the ocean front. The mechanical distortion of the hairs in the organ of Corti changes the ION migration through pores in the CELL MEMBRANE generating a transmembrane potential that will eventually exceed the DEPOLARIZATION threshold, at which point causing the cell to send off an ACTION POTENTIAL that contains the binary indication of a received frequency that is specific for the location of the cell that stretched (i.e., location-specific frequency encoding) (see Figure I.18).

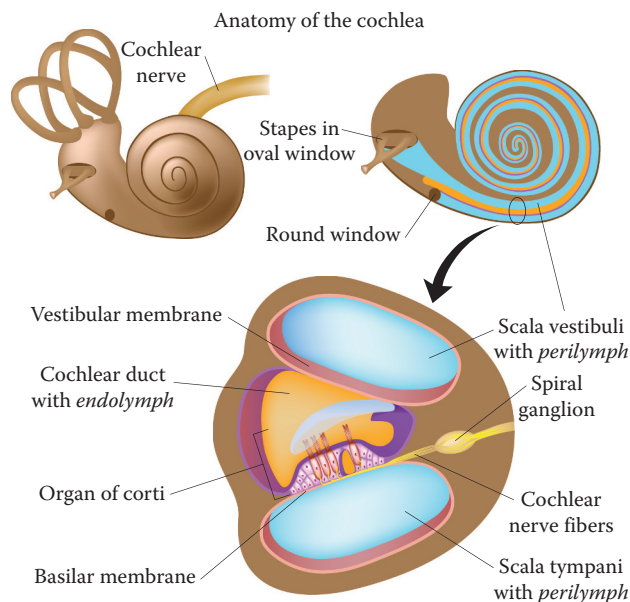
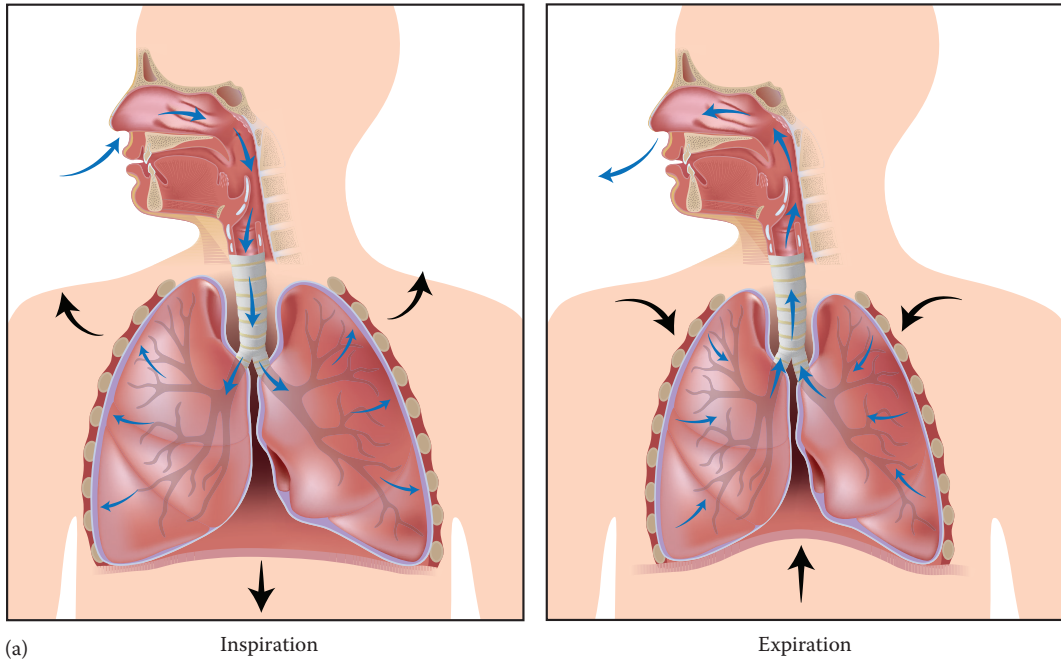


Figure I.18 The inner ear with operational aspects and components.

Inspiratory capacity

[biomedical, fluid dynamics] During TIDAL BREATHING, the maximum volume of GAS that can be inhaled after a normal exhalation. The average inspiratory capacity is 3500 ml (see Figure I.19).



Gas exchange

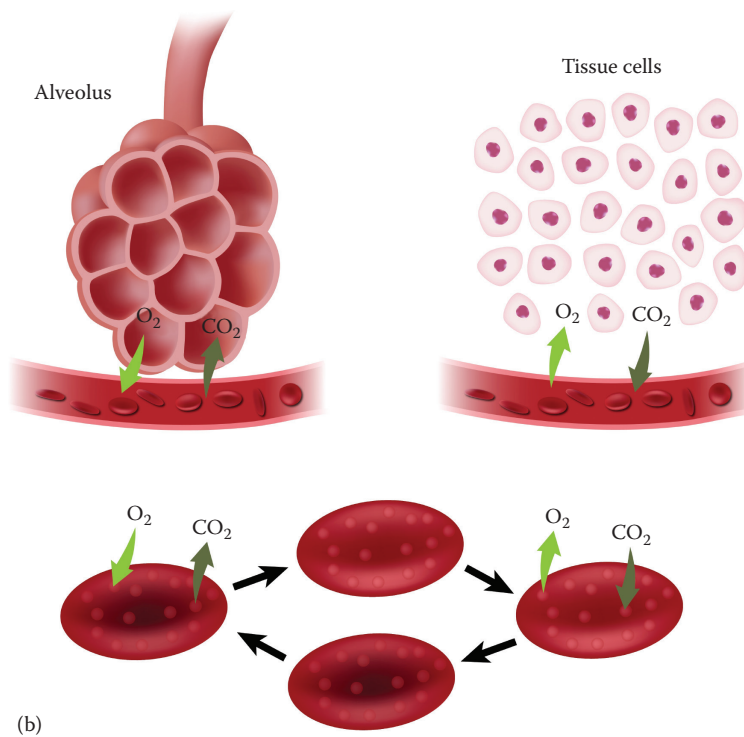


Figure I.19 (a,b) Respiration, gas exchange. The volume respiration diagram uses the following abbreviations: FRC, functional reserve capacity, the volume remaining in lungs at resting expiratory levels: the combined volume of the alveoli: (60%–70%) as well as the respiratory bronchioles and alveolar ducts (30%–40%): also referred to as the alveolar volume A.

Inspiratory reserve volume

[biomedical, fluid dynamics] Excess quantity of AIR that can be inhaled after normal inhalation during gentle TIDAL BREATHING. Inspiratory reserve volume and other tidal breathing parameters can be measured with a spirometer (see [Figure I.20](#)).



Figure I.20 Man breathing in spirometer in order to establish the lung function.

Insulator

[atomic, electronics, general] A material made of ELEMENTS with specific ELECTRON configuration. An ATOM has the electrons arranged according to the BOHR ATOMIC MODEL with electrons in specific allowed ENERGY LEVELS or ORBIT SHELLS. In comparison with either INSULATOR or CONDUCTOR, the electron configuration falls between these two. In an insulator, the CONDUCTION BAND containing free electrons is unpopulated

and separated by a forbidden gap from the VALENCE BAND, whereas in conductor configuration the valence band is overlapping the conduction band, hence populating the conduction mechanism of action with free electrons (see [Figure I.21](#)).



Figure I.21 Insulation for above-ground residential high-voltage power cord separation from metal support mast.

Integrated circuits

[electronics, general] See **IC**.

Integrins

[biomedical, chemical] A type of transmembrane-binding receptor in biology that provides cell-to-cell interaction. The full interaction mechanism can be divided into four types of receptors: CADHERINS, selectins, INTEGRINS, and IMMUNOGLOBULIN SUPERFAMILY. Integrins are molecular groups that bind to specific ligands across the extracellular space toward the target CELL. Some integrins may rely on ACTIN filaments. Integrins are, for instance, found on white BLOOD cells.

Intensity (I)

[biomedical, electromagnetism, energy, thermodynamics] The AMPLITUDE of a phenomenon squared, measure of the magnitude of ENERGY. The amplitude of an acoustic WAVE is one of the most common examples. Acoustic LOUDNESS is generally presented in DECIBEL units. The decibel is a unit that was introduced in 1923 and is a logarithmic scale (10-log), in $dB = 20 \log I$, but also found as $dB = 10 \log I$ and is generally measured against a baseline value as a relative MAGNITUDE. The decibel was originally designed to quantify

the SIGNAL strength and respective loss in telephone communications by the Bell laboratories. The original “bell” unit was ten times the power loss over 1 mile of cable at 795.8 Hz, expressed as the ratio of the signal strength at the distal end with respect to the input power. Alternatively, intensity can measure the number of particles collected with respective energy content (incorporating both PARTICLE velocity and quantity). For ELECTROMAGNETIC RADIATION, the concept of intensity is inappropriate due to the combination of two energy sources: electric and MAGNETIC FIELD. For electromagnetic radiation, the use of radiance or fluence is the standard.

Interference

[acoustics, optics, theoretical] The superposition of multiple WAVES, primarily from a single source that is split and recombined. The troughs of the WAVE pattern will cancel out against the crests in overlapping locations, which is a propagation path length and WAVELENGTH ($\lambda = v/\nu$, where v is the propagation velocity and ν the OSCILLATION frequency) related phenomenon. Positive interference (RESONANCE) will take place when the path difference is a whole number times the wavelength ($n\lambda$), while negative interference (cancellation) will occur at odd number intervals times the half-wavelength ($(2n+1)(\lambda/2)$). The INTERFERENCE term of two waves (with the same frequency) expressed as $A_1 = A_{01} \sin(\omega t + kx + \phi)$ (where $\vec{x}$ the DISTANCE traveled from the source in a selected frame of reference, $\omega = 2\pi\nu$ the ANGULAR FREQUENCY, ν the frequency, $k = 2\pi/\lambda$ the wave number, and ϕ the PHASE locally of the wave) yields the superposition interference ($I = A^2$) for intensity with the term $2\sqrt{I_1 I_2} \cos[k(x_1 - x_2) + \phi_2 - \phi_1]$; this yields for the total wave pattern $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos[k(x_1 - x_2) + \phi_2 - \phi_1]$. For consistent interference, the source will need to be coherent; otherwise, the interference will be randomized by the shifts in phase for each component. For optical interference, see OPTICAL COHERENCE TOMOGRAPHY (see Figure I.22).

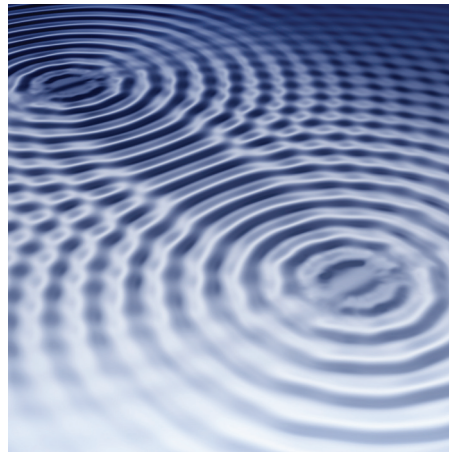


Figure I.22 Illustration of the concept of interference of surface wave on liquid.

Interferometer

[atomic, nuclear, optics] A device used in ELECTROMAGNETIC RADIATION and quantum-mechanical PARTICLE waves (de Broglie principle) INTERFERENCE to provide details about the WAVE process and the media the waves are traveling in. Interferometers specifically use a single source which is split into two separate paths, one reference and one measurement path. Optical interferometers have been designed over the past century, for instance, the MICHELSON INTERFEROMETER, Rayleigh interferometer, and the FABRY-PÉROT INTERFEROMETER. The Fabry-Perot interferometer is specifically used as a selection tool, isolating a single operating condition as a viable option, such as used in the Q-switched laser (also see INTERFERENCE and OPTICAL COHERENCE TOMOGRAPHY). The Michelson interferometer is one of the most used and relatively elementary

in construction, also the first known optical interferometer constructed in 1887 by ALBERT ABRAHAM MICHELSON (1852–1931). The Michelson interferometer provided one of the experimental means to verify aspects of the SPECIAL THEORY OF RELATIVITY (see Figure I.23).

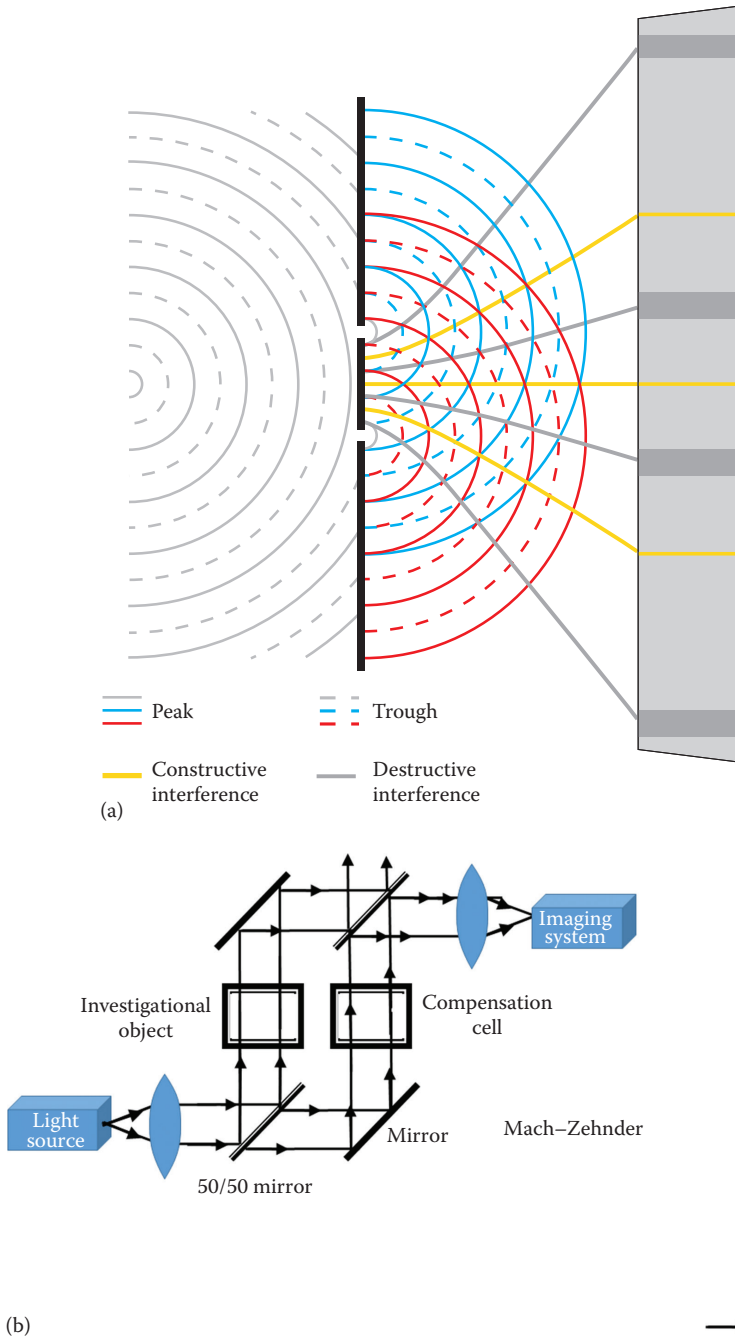


Figure I.23 Representation of one of the choices in interferometer design. (a) Rudimentary optical device with interferometric capacity: double slit and (b) optical interferometer: Mach-Zehnder interferometer. (Continued)



(c)

Figure I.23 (Continued) Representation of one of the choices in interferometer design. (c) Radio interferometer, submillimeter array in Mauna-Kea, Hawaii.

Intermolecular forces

[atomic, chemistry, quantum, solid-state] On a nuclear level, the anticipated forces are primarily repulsive due to the composition of protons and neutrons, and on the whole the electronic forces are only forming a portion of the attractive and repulsive system in the atomic and molecular structure. The classification of forces operating on the atomic and molecular level is as follows: gravitational forces; weak force; electromagnetic force, and strong force. The gravitational force and electromagnetic force generally have unlimited range, whereas the **WEAK FORCE** has a range in the order of 10^{-17} m, respectively, the strong force range is in the order of 10^{-15} m. On an atomic level, this translates into **DIPOLE** forces that rely on charge distribution as well as covalent forces that involve “sharing” electrons between atoms. The covalent force is a very strong force. Hydrogen bonds are very strong (one of the strongest intermolecular bonds), since they resemble “proton sharing,” mimicking nuclear interaction.

Internal combustion engine

[thermodynamics] A **ENGINE** that burns fossil fuels and may operate on a four-stroke or two-stroke mechanism of compression and **EXPANSION** next to certain rotary engine designs. Diesel engines use compression to generate enough heat for autocombustion, whereas propane (natural gas) or gasoline engines require a spark plug that is linked to a timing mechanism that initiates a spark to provide the ignition of the hydrocarbon–oxygen mixture resulting in **OXIDATION** and is an **EXOTHERMIC REACTION**. The combustion

provides the ENERGY to perform work, displacing a cylinder that is transferred to an axle, primarily through a gear system, that will make the device perform a mechanical action of movement or to rotate a magnet/coil in an electrical GENERATOR system (see [Figure I.24](#)).

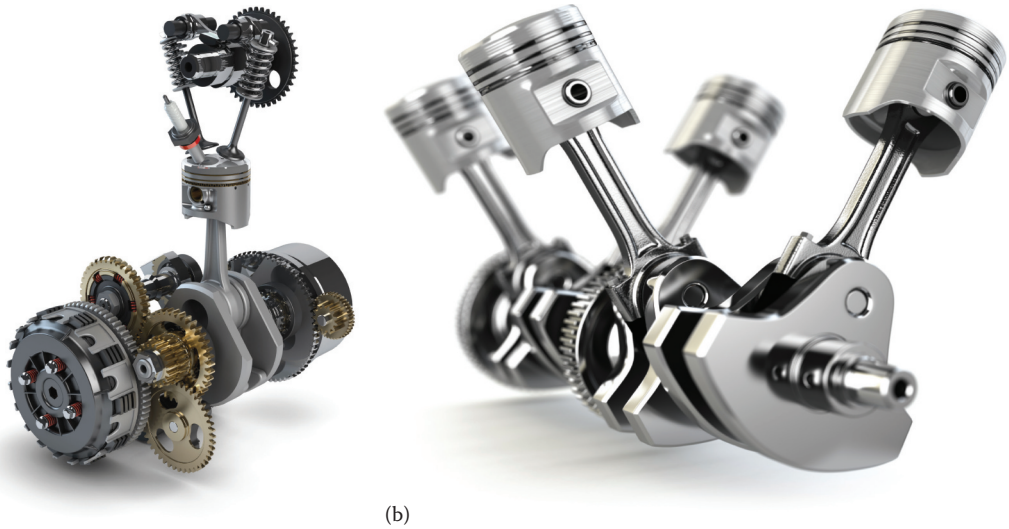


Figure I.24 (a,b) Internal combustion engine.

Internal conversion

[atomic, energy, nuclear] In the process of ELECTRON CAPTURE, the convergence of a PROTON and the captured electron are transformed into a NEUTRON and a NEUTRINO $p_{\text{proton}} + e^- = n_{\text{neutron}} + \bar{\nu}$. The electron capture process may result in gamma RADIATION, which can in turn be captured by an orbital electron. The transfer of ENERGY to the electron will result in ejection of the electron. AUGER ELECTRONS are the direct result of INTERNAL CONVERSION associated with CHARACTERISTIC X-RAY radiation (see [Figure I.25](#)). A nuclear mechanism that involves the interaction of the WAVE function of a lower shell electron with the NUCLEUS, converting nuclear "RESONANCE" energy into kinetic energy, resulting in the emission of the lower shell electron (not emission of the VALENCE electron) at relatively high energy. The internal conversion can be regarded as the exchange of energy through a virtual PHOTON, "emitted" (virtual gamma radiation, with energy equivalent to the transition energy within the nucleus minus the electron binding energy for the ATOM) by the nucleus.

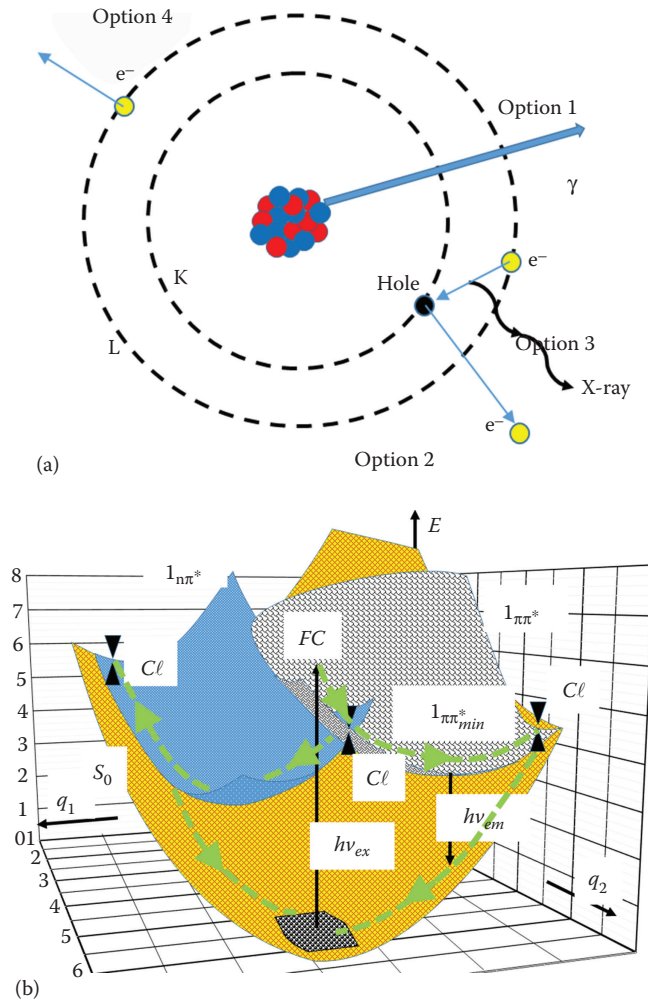


Figure 1.25 Diagram of the energy and constituent restructuring process under internal conversion.

(a) A schematic of de-excitation mechanism in an atomic nucleus. The nucleus can be de-excited by emission of X-ray (option 1) and emission of a closely bound electron from the atom, most prevalent is the emission of a K-electron, however an electron in the L-shell or a higher shell can also be emitted, that is, conversion electron (option 2). The electron hole left behind is subsequently filled by another electron, with the potential for X-ray emission photon (option 3), or initiates the emission of an Auger electron (option 4). (b) Internal conversion in molecular form. Schematic of a potential nonradiative decay mechanism for the pyrimidines represented in two arbitrary coordinate axes, as a function of energy. After the molecule has been excited to the $1_{\pi\pi^*}$ state (black/white pattern), the energy population migrates toward the minimum within this state ($1_{\pi\pi^*min}$), passing through a $C\ell$ condition with the 1 state, highlighted in blue. Upon leaving the condition of $C\ell$, the energy balance can migrate either toward $1_{\pi\pi^*min}$ with the potential for the emission of fluorescence (with total energy: $h\nu_{em}$; with h the Plank's constant, and ν_{em} the emission frequency), alternatively the decay will branch to the $(1_{\pi\pi^*}/S_0)C\ell$ (path outlined to the right of center), or goes toward the minimum of the $1_{\pi\pi^*}$ state (path on the left). After the molecule has spent time in the $(1_{\pi\pi^*}/S_0)C\ell$ state it will relax to the black checked patch in S_0 (outlined by the yellow energy "shell"). The latter may only be achieved by means of tunneling.

Internal energy (U)

[biomedical, fluid dynamics, general, thermodynamics] The amount of heat produced by a system minus the work performed. An ISOLATED SYSTEM does not exchange heat nor does it perform work, hence has constant internal ENERGY. The sum of the chemical, kinetic, potential, nuclear, and all other known and yet unknown energies of the particles that make up a system. Internal energy is a fundamental state variable for a system and signifies the MOLECULAR MOTION (*also see* FIRST LAW OF THERMODYNAMICS).

Internal pair production

[nuclear] Energetic interaction of the lowest electron orbit with the nuclides that releases an electron–positron pair instead of emission of gamma RADIATION. The ENERGY content is the NUCLEON energy minus the BINDING ENERGY of the electron in the lowest orbit.

International Bureau of Weights and Measures

[general] An organization responsible for standards and calibration of accepted quantities for the description and definition of specific phenomena and objects.

Invariable plane

[astronomy/astrophysics, computational] The gravitational action of the Sun results in a PRECESSION of satellites about the normal to the invariable plane. The invariable plane is inclined by an ANGLE θ_i with respect to the planetary equator, expressed as $2J_2 \sin(2\theta_i) = (\omega_\odot/\omega_i)^2 (\sqrt{1-e^2})^{-1} \sin\{2(\theta_e - \theta_i)\}$, where J_2 is the second-order BESSEL FUNCTION, $\omega_\odot$ the earth's angular velocity, ω_i the angular velocity of the SATELLITE in orbit, $\sqrt{1-e^2}$ the ratio of the major axis of the elliptic orbit with respect to the minor axis (subject to Kepler's rule), and θ_e the obliqueness of the satellite axis with respect to the planetary orbit; which defines the interaction to the lowest order. The invariable plane normal vector lies between the planetary SPIN vector and planetary orbit normal. These three respective normals are coplanar. The INVARIABLE PLANE is also known as the Laplacian plane (see Figure I.26).

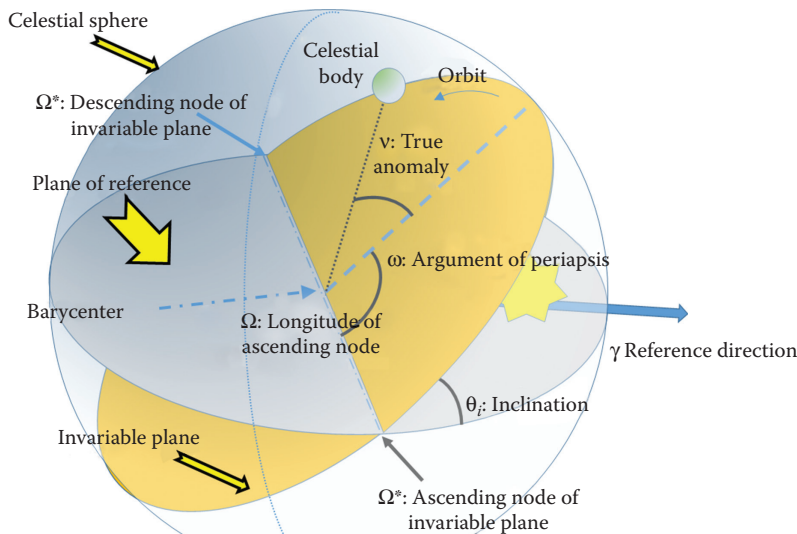


Figure I.26 Geometric representation of the invariable plane.

Inversion

[acoustics, biomedical, geophysics, imaging, molecular, solid-state, theoretical, thermodynamics] An inversion generally refers to a process that changes sign or direction or has a discontinuity when the boundary conditions change. Inversion applies specifically to the areas of ACOUSTICS, METEOROLOGY, and molecular QUANTUM MECHANICS, each in its own specific manner. The field of acoustical inversion ranges from seismologic imaging to biological imaging. In acoustics, inversions refer to the process where SEISMIC phenomena (e.g., acoustic probing) provide reflections of the pressure WAVE based on geologic discontinuities. Seismic inversion can provide an indication of natural GAS or OIL reservoirs imbedded in rock formations. The lower density LIQUID or GAS bordering a solid rock will provide a PHASE shift in the acoustic waveform. In acoustic imaging for medical applications and in nondestructive testing, the same inversion

can yield mechanical information about abrupt changes in structural density, highlighting soft tissues. Inversion mode imaging for biological applications specifically provides insight in fetal FLUID structures. In METEOROLOGY, inversion indicates a layered ATMOSPHERE with a temperature profile that instead of decreasing with altitude has an INVERSION POINT where the temperature is higher than at lower altitude. Inversion layers can support violent thunderstorms due to the rapid condensation. In MOLECULAR DYNAMICS, specifically molecular vibration, an ENERGY hierarchy can be recognized from spectroscopic analysis. The VIBRATION process can be separated into vibrational and rotational processes. The vibrational spectral lines are in the INFRARED (1000 cm^{-1} region), while the rotational transitions are in the microwave (1 cm^{-1} region). The vibrational transitions are separated into an energy POTENTIAL WELL diagram by a POTENTIAL BARRIER around the parabolic minimum, yielding two respective minima. The MICROWAVE transitions for certain molecules can switch minima, this is referred to as inversion. The spectral profile will illustrate the switches in a representative inversion spectrum for the molecular group in question. In the molecular inversion process, the formation of “instantons” provides dominant TUNNELING paths derived based on the QUANTUM dynamical Feynman path-integral. Instantons are the energy “surfaces” of unstable orbits with respect to inverted potential energy surfaces (see Figure I.27).

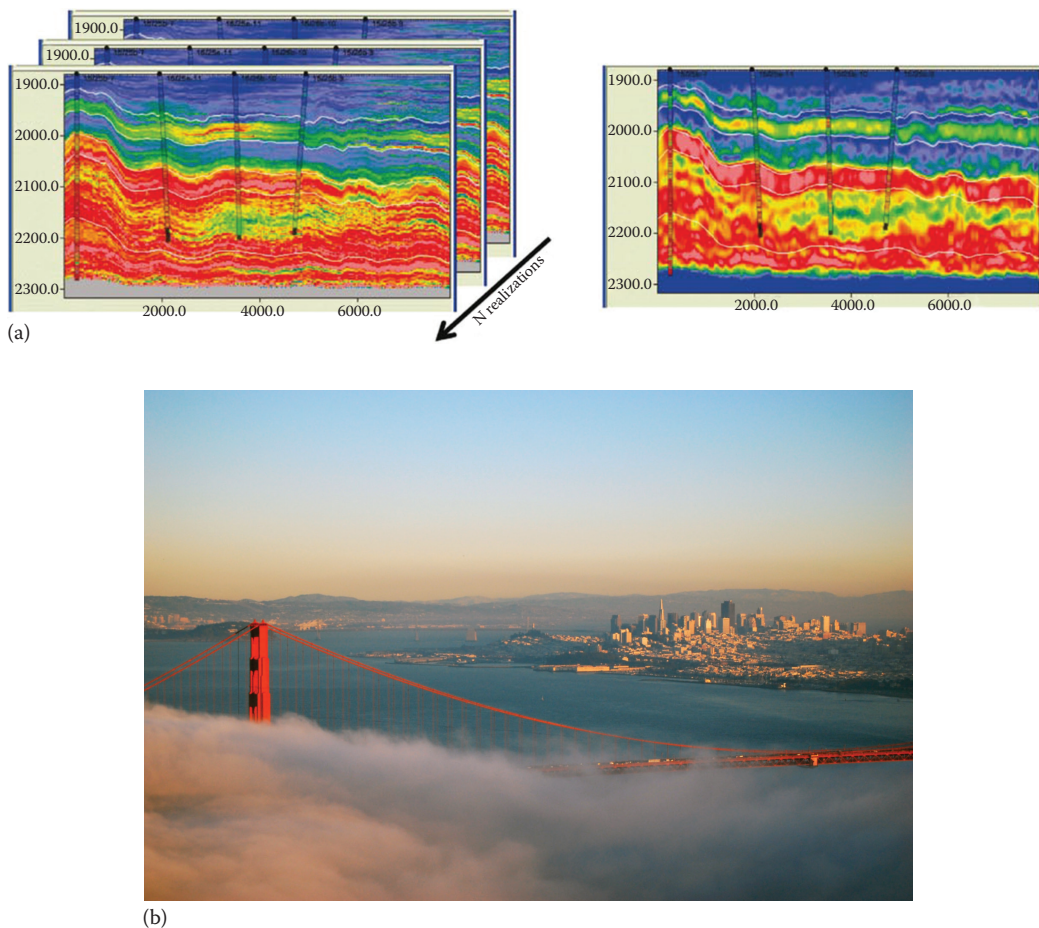


Figure I.27 (a) Example of one of the forms of atmospheric (meteorological) inversion and (b) acoustical impedance image of seismic inversion. (Courtesy of Ikon-Rokdoc, Ikon Science; The Causeway, Teddington, London, United Kingdom.) The acoustic impedance graphs indicate three geostatistical inversion realizations (a, left) as well as the deterministic acoustic impedance representation (a, right) over the same arbitrary line. As part of the geostatistical inversion, the match at the wells is verified, next to the fact that the frequency content is quantifiably higher. *(Continued)*



(c)

Figure I.27 (Continued) (c) Illustration of the potential energy surface inversion with respect to molecular inversion producing a tunneling effect with respect to the water-trimer (in a water cluster, the water molecules are capable of forming hydrogen bond networks with one potential configuration the trimer: D_2O_3), what is known as an “instanton.” (Courtesy of Jeremy Richardson, Stuart C. Althorpe, and D. J. Wales, The Althorpe Group; University of Cambridge, Cambridge: United Kingdom.)

Inversion curve

[thermodynamics] The locus of the INVERSION points associated with the VAPOR phase of the respective constant enthalpy ($h_e = U + PV$ for the individual constituents of the system H , where U is the internal ENERGY, P the pressure, and V the volume) processes in the temperature versus pressure diagram. Under constant enthalpy, the process is defined by the JOULE–THOMPSON COEFFICIENT $\mu_{JT} = \left(\partial T / \partial P\right)_{h_e}$, with T the temperature (in KELVIN), in which case the inversion curve separates the positive from the negative values (*also see JOULE–KELVIN EFFECT and INVERSION POINT*) (see [Figure I.28](#)).

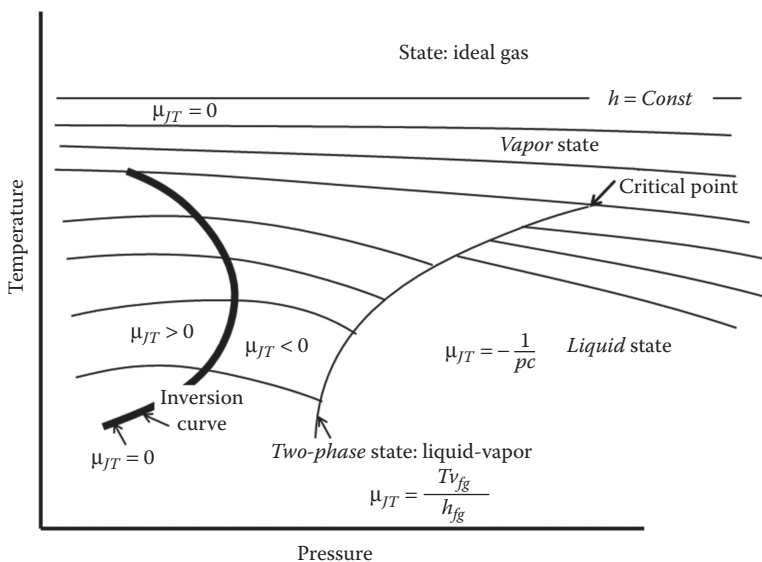


Figure I.28 Inversion curve for the vapor phase of.

Inversion point

[thermodynamics] In a system of throttles and valves, the temperature versus pressure diagram for the enthalpy, the vapor PHASE associated with the constant-enthalpy curve will provide a maximum value when the temperature is sufficiently low; these locus are the inversion points for the processes (*also see* INVERSION CURVE).

Inviscid flow

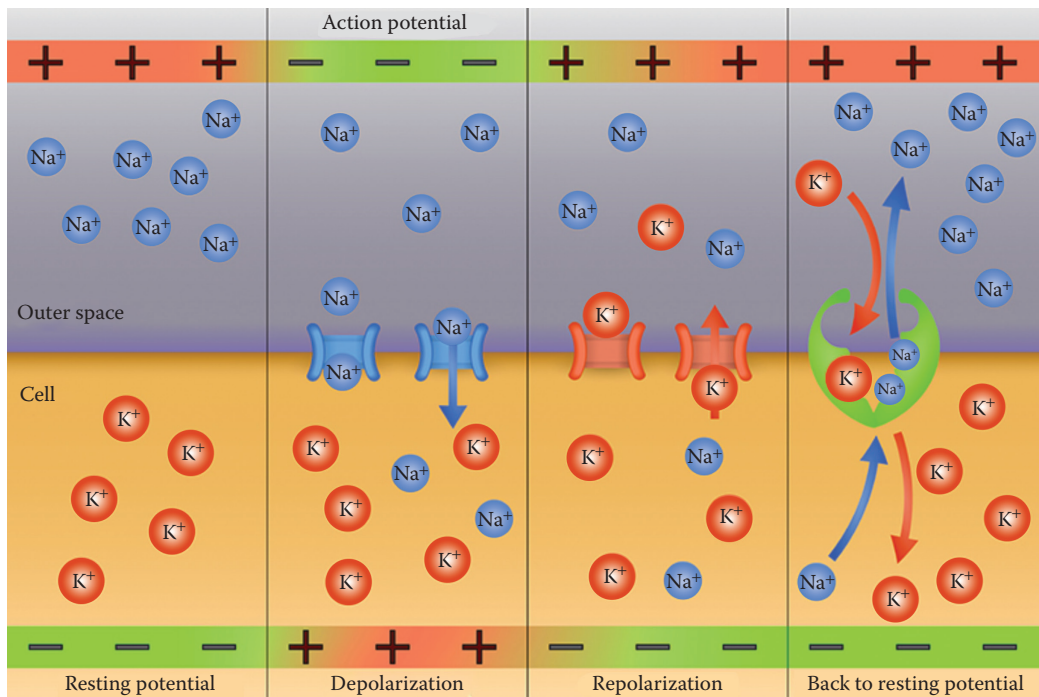
[fluid dynamics] Fluid flow for a FLUID with no APPARENT VISCOSITY, ideal fluid. FLOW pattern generally attributed to conditions with high REYNOLDS NUMBER, $Re \gg 1$.

Ion

[atomic, nuclear, solid-state] An ATOM, atomic particle, or chemical radical (i.e., group of chemically combined atoms) having a net electrical charge, either negative or positive, respectively, resulting from an excess or deficiency of electrons.

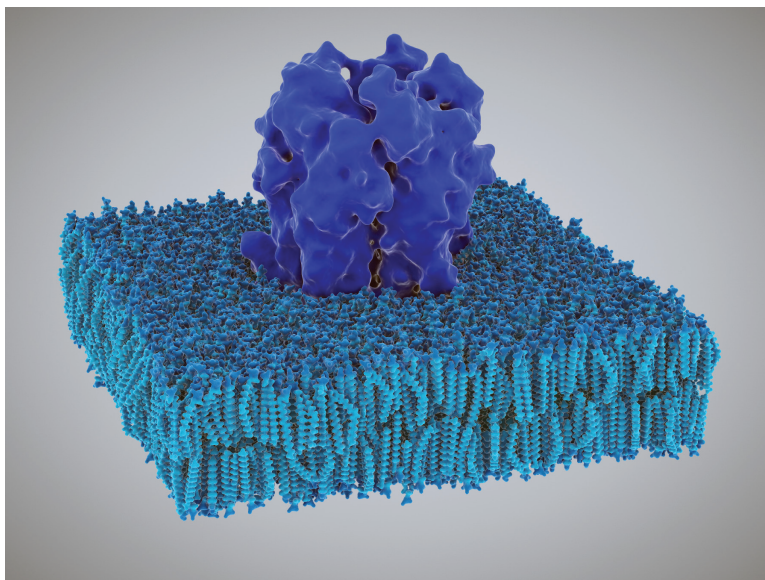
Ion channel

[biomedical, chemical, thermodynamics] In the MEMBRANE of biological cells, there are ION passages. The channels are voltage-mediated gates that regulate transmission of certain ions or molecules by activating changes in the transmembrane electrical potential or by activating extracellular or intracellular transport molecules, called LIGANDS, that attach to the select ions and molecules. The membrane potential directly depends on the respective ion concentrations on opposite sides of the CELL MEMBRANE, for example, POTASSIUM (K^+), sodium (Na^+), and chlorine (Cl^-). The transmembrane-resting potential is based on the NERNST EQUATION, further expanded into the GOLDMAN VOLTAGE EQUATION (see Figure I.29).



(a)

Figure I.29 Representation of the cellular ion channel for biological media: (a) simulation of transmembrane ion transport. (Continued)



(b)

Figure I.29 (Continued) Representation of the cellular ion channel for biological media: (b) impression of the ion channel in detail.

Ion mobility

[atomic, molecular, solid-state] The velocity achieved by an ION moving through a gaseous medium when an external unit electric field is applied μ_{ion} . For a mixture, this translates into $\mu_{\text{ion}} = (\sum_{i=1}^n f_i / \mu_{\text{ion},i})^{-1}$, where f_i is the fractional value for constituent i , and $\mu_{\text{ion},i}$ the respective ION MOBILITY (BLANC'S LAW). The reduced ion mobility is the mobility in the parent gas, which is often defined for a density ($\rho_{\text{mol}} = 2.69 \times 10^{25} \text{ m}^{-3}$) of and is in the order of $10^{-4} \text{ m}^2/\text{sV}$, for instance, for a LITHIUM ion in helium gas $\mu_{\text{Li}^+} = 25.6 \times 10^{-4} \text{ m}^2/\text{sV}$ at normal (standard) pressure and temperature. The mobility depends on the purity of the GAS and is also a function of the electric field strength (E) and the Loschmidt constant (N_L), describing the moles per volume at standard pressure and temperature): E/N_L .

Ion pair

[chemical, solid-state] Halides and metallic molecules generally consist of an electronegative and electro-positive ATOM (-group), consisting of a pair, which can be separated. Salt SOLUTION forms an equal amount of positive and negative ions, for example, NaCl.

Ion-conductance microscopy

[imaging] An imaging system that resembles the ELECTRON MICROSCOPE, however using conducting free-flowing ions as an imaging mechanism. The ion-conductance microscope however does not require VACUUM conditions and can be used to study live biological media. The concept is a merger between the principles of the electron microscope and near-field microscopy. The ion-conductance microscope relies on a pipette that is in close proximity to the biological medium that delivers the low-voltage acceleration potential, less than 1 V range. Image acquisition is provided by scanning of the ION release pipette in a preset pattern to gradually fill a database array. The locally established ion-flow can provide both anatomical (topographical)

and physiological details based on the selection of ions with respect to the cellular activities under investigation (see [Figure I.30](#)).

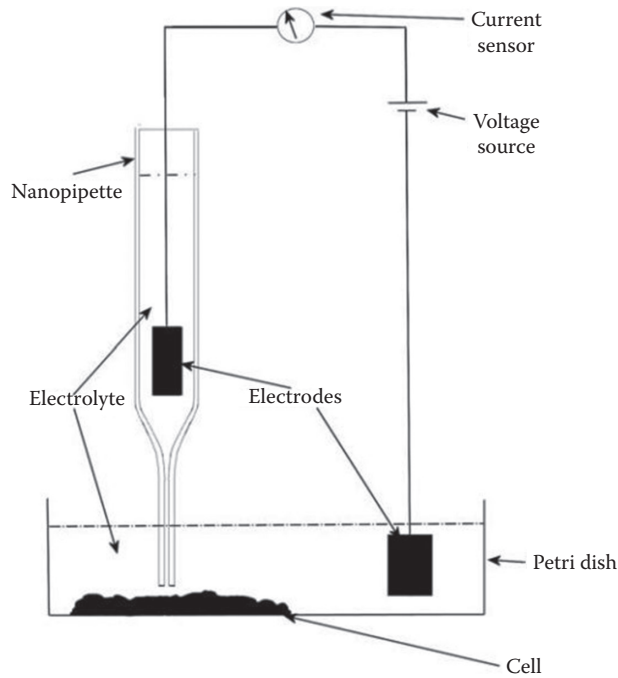


Figure I.30 Schematic diagram of the operation for an ion conductance microscope.

Ionization

[atomic, biomedical, chemical, electromagnetism, energy, nuclear, solid-state] The act or result of any process by which a neutral ATOM or MOLECULE acquires either a positive or a NEGATIVE CHARGE, respectively, emits or acquires an electron. It is the process of removal or addition of an electron to an atomic structure, primarily in the VALENCE BAND of the outer shell of the atom, process of creating an ION (*also see SPARK, CORONA, and LIGHTNING*) (see [Figure I.31](#)).

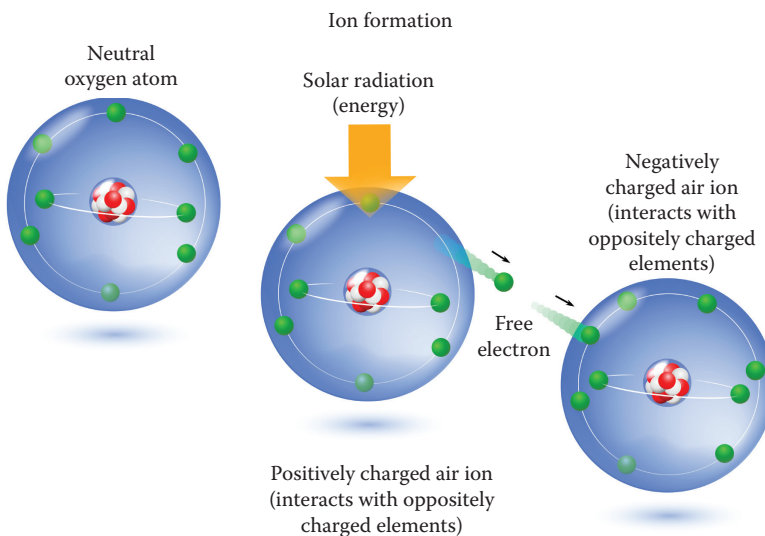


Figure I.31 Schematic representation of the process of ionization.

Ionization energy

[atomic, nuclear, solid-state] The electronic potential (V_i) that can result in the formation of an ION based on the internal ENERGY configuration of an ATOM, with the individual charge energy for the respective PHASE, the atom (ϵ_a), electron (ϵ_e), and the ion (ϵ_i) to yield $V_i = \epsilon_e + \epsilon_i - \epsilon_a$ (also see SAHA EQUATION).

Ionization potential

[general] The electrical potential necessary to separate one (1) electron from an ATOM with the formation of an ION having 1 elementary charge.

Ionosphere

[atomic, energy, geophysics, thermodynamics] Layer of the Earth's atmosphere. In the ionosphere, a considerable number of atoms and molecules have been ionized as a result of the interaction with solar ENERGY, primarily in the ULTRAVIOLET and shorter wavelength region. The ionosphere additionally contains a large number of free electrons. The ionosphere extends from an altitude of approximately 50 to 1,000 km. In RADIO communications, the ionosphere can provide a transition layer with a high-reflection coefficient. Radio WAVE reflections from the ionosphere are primarily noticeable for long wave radio transmissions, allowing propagation half-way around the world without the need for amplifiers (Note: cell-phone communications require support antennas serving as repeaters to be placed at regular intervals to ensure reliable communications) (also see AURORA) (see Figure I.32).

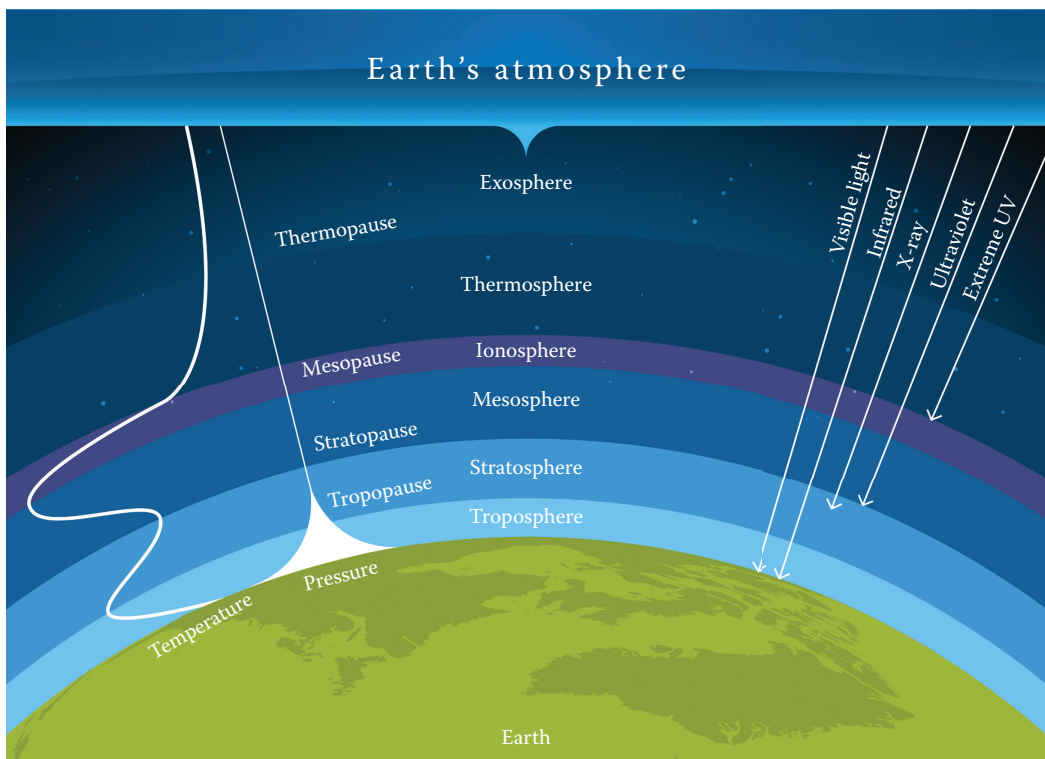


Figure I.32 The Earth ionosphere in reference to the classification of atmospheric layers.

Iron

[biomedical, chemical, solid-state] A metal ELEMENT: ${}^{56}_{26}\text{Fe}$. Iron is the most common element on the planet EARTH, forming most of the core and shell, by mass. The iron ion (Fe^{2+}) is an elementary component for human life since it forms the foundation for the hemoglobin affinity to oxygen (O_2): $\text{C}_{2952}\text{H}_{4664}\text{O}_{832}\text{N}_{812}\text{S}_8\text{Fe}_4$.

Irradiance (I)

[general] The ENERGY flux (i.e., PHOTON energy) crossing the surface of a volume of medium, which is equal to the RADIANT ENERGY FLUENCE RATE. When the incident FLUX is orthogonal to the surface, this is equivalent to the FLUENCE RATE (see RADIANT ENERGY FLUENCE RATE, RADIANCE, and POYNTING VECTOR).

Irrotational flow

[fluid dynamics] Flow in which the individual “fluid particles” will not rotate around their axis (MACROSCOPIC spin equivalent); however, the entire FLOW may still form a rotation, that is, TURBULENCE. This is one of the conditions defining the boundary conditions for Bernoulli flow. Irrotational flow is defined by considering a loop between two separate points “(flow particles)” in the flow: A and B, where A and B are connected by means of two separate paths: ACB and ADB, respectively, where ACBDA forms a closed loop. In irrotational flow, the following now hold true for the VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$): $\int_{ACB} \vec{v} \cdot d\vec{r} + \int_{ADB} \vec{v} \cdot d\vec{r} = 0$. In this case, the velocity potential ϕ_r is a SCALAR function linked to the local velocity vector as $\vec{v} = -\nabla\phi_r$, the gradient in the VELOCITY POTENTIAL, and the irrotational behavior is set as $\omega_{\text{rot}} = \nabla \times \vec{v} = 0$. Adding incompressibility will yield the LAPLACE EQUATION, since also $\nabla \cdot \vec{v} = 0$, providing $\nabla^2\phi_r = 0$.

Irrotational (curl-free) vector field

[computational, fluid dynamics] A fundamental component of HELMHOLTZ DECOMPOSITION in vector calculus. In three-dimensional space, the vector field composed of sufficiently smooth, rapidly decaying vectors can be decomposed into the sum of two “orthogonal” components, one consisting of an IRROTATIONAL (CURL-FREE) VECTOR FIELD and the second segment composed of rotational (divergence-free) or solenoidal vector field (see CURL-FREE VECTOR FIELD).

Isaac Newton (1642–1727)

[fluid dynamics, general, mechanics, nuclear, solid-state] See NEWTON, ISAAC, SIR (1642–1727).

Isentropic

[fluid dynamics, thermodynamics] A system or process with constant entropy (S), thus $dS = 0$. Under these conditions, the following applies: $dU = -PdV$, where U represents the internal ENERGY, P the pressure, and V the volume; respectively, $dU = \delta Q^{\leftarrow} - \delta W^{\rightarrow}$, where $Q^{\leftarrow}$ is the FLOW of heat into the system and $W^{\rightarrow}$ the work performed by the system. From this, it follows that only under certain conditions, an ISENTROPIC PROCESS is reversible and adiabatic.

Isentropic flow

[fluid dynamics] Flow process that has ISENTROPIC characteristic, primarily confined to a system where the FLOW changes gradually and in relatively small increments. This kind of flow process is reversible and based on the SECOND LAW OF THERMODYNAMICS inherently isentropic. The generation of SOUND waves is an ISENTROPIC PROCESS. One specific example is the NOZZLE flow going from subsonic to supersonic. When there is “shock” involved or oblique flow than the conditions are no longer supporting isentropic flow (see [Figure I.33](#)).

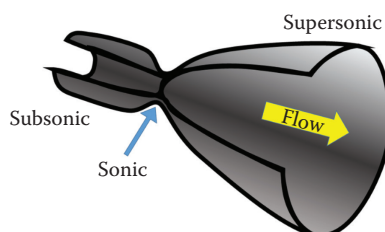


Figure I.33 Representation of Isentropic flow parameters.

Isentropic process

[thermodynamics] See ISENTROPIC.

Entropy

[general] Constant MAGNITUDE of disorder of the molecular states of a thermodynamic or mechanical system. Consider that entropy is the representation of the possible energetic states (N_{mol}) on molecular scale $S = k_B \log N_{\text{mol}}$, where $k_B = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the Boltzmann coefficient.

Ising, Ernst (1900–1998)

[computational] A physicist from Germany. Ising's work revolved around MAGNETIC moments and the special case where they line up in a linear chain. The (atomic) magnetic SPIN moments, in this case, can take two states: “1” or “up” and “0” or “down”, while their interactions are coupled to the nearest neighbors in a LATTICE structure (see [Figure I.34](#)).

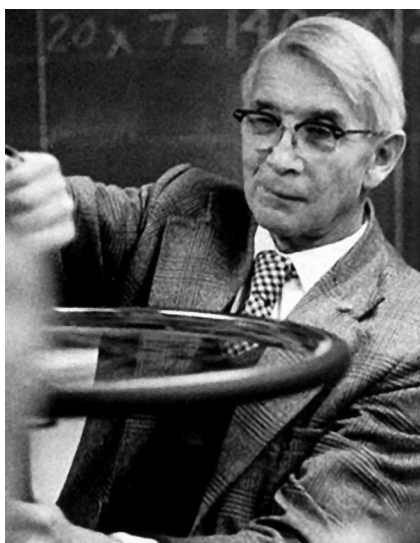


Figure I.34 Ernest Ising (1900–1998).

Ising model

[computational] A mathematical model of FERROMAGNETISM in statistical MECHANICS named after the implementer ERNST ISING (1900–1998) in 1925, following the lead of his professor Wilhelm Lenz (1888–1957) who introduced the concept in 1920. The Ising model provides theoretical support for PHASE transitions. The two-dimensional model is much more complex than the one-dimensional model.

ISO standards

[biomedical, electromagnetism, general, mechanics] Engineering normalization, standardization, qualification, and COMPLIANCE definitions introduced and regularly updated by the International Organization for Standardization (ISO), a multinational association with its headquarter in Switzerland. The ISO body and standardization was introduced in 1947. The most well-known ISO standards for production and quality management and the requirements for the facility are ISO 9000, respectively, ISO 9001. In total, there are close to 400 documented standard specification documents with targeted reference numbering. In order to be accepted and recognized for the manufacturing of certain devices and systems, corporations will be required to obtain certification for the appropriate and pertinent ISO standards.

Isobar

[nuclear, thermodynamics] A graphical representation of a system showing lines for processes that occur under constant pressure in a T – V (temperature vs. volume) diagram. In nuclear PHYSICS, the term isobar refers to nuclides with identical mass number (A): $A = Z + N$, where Z is the atomic number (i.e., the number of protons in the NUCLEUS), and N the NEUTRON number (see Figure I.35).

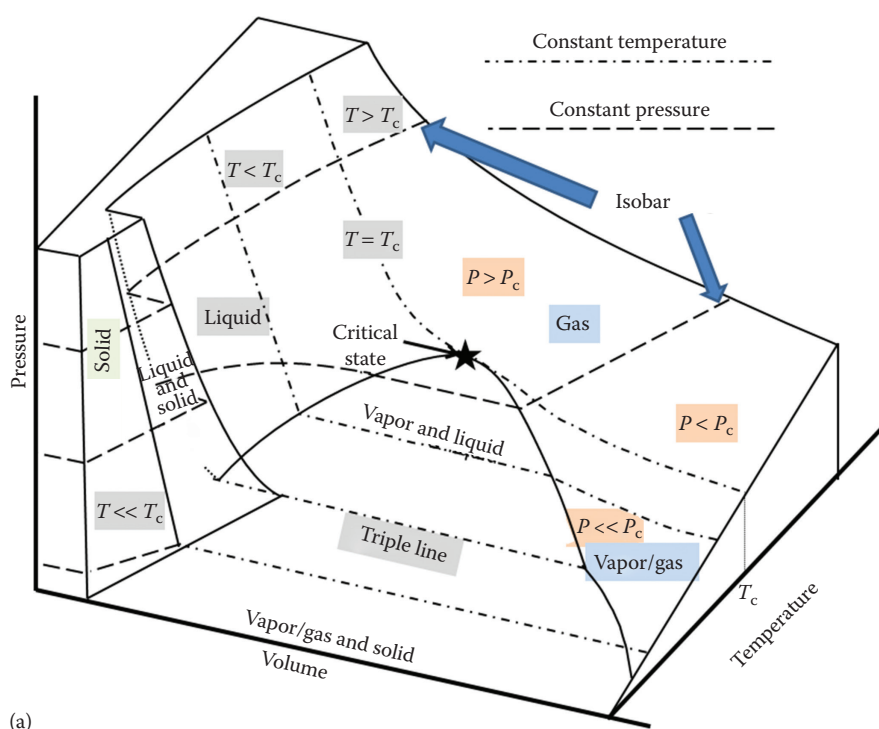
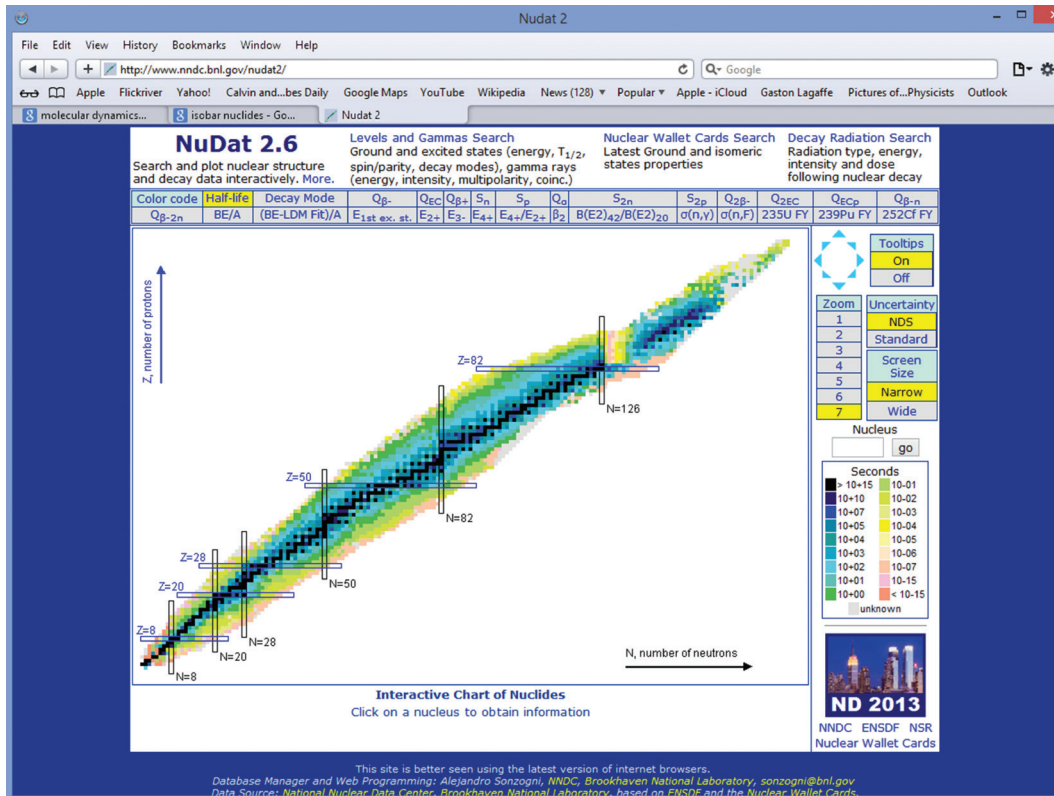


Figure I.35 (a) Graphical illustration of constant pressure in a temperature versus volume diagram with respect to fluid conditions, specifically for water. (Continued)



(b)

Figure I.35 (Continued) (b) Nuclide isobar chart. The isobars in this chart are represented by the diagonal lines crossing from the upper left of the diagram to the lower right. Stable nuclides are represented by the line of beta-stability, shown in black. The individual pockets of noncontinuous isotopes are a consequence of the Mattauch isobar rule. (Data Source: National Nuclear Data Center, Brookhaven National Laboratory, based on ENSDF and the Nuclear Wallet Cards.)

Isobaric change

[fluid dynamics] Temperature change with associated change in volume that holds a constant pressure for a FLUID. Isobaric changes are found in two stages of the reversible RANKINE CYCLE, one single stage of the DIESEL CYCLE and two segments of the JOULE-BRAYTON CYCLE.

Isochor

[thermodynamics] A graphical representation of a fluid-solid system showing lines for processes that occur under constant volume in a P – T (pressure vs. temperature) diagram (see Figure I.36).

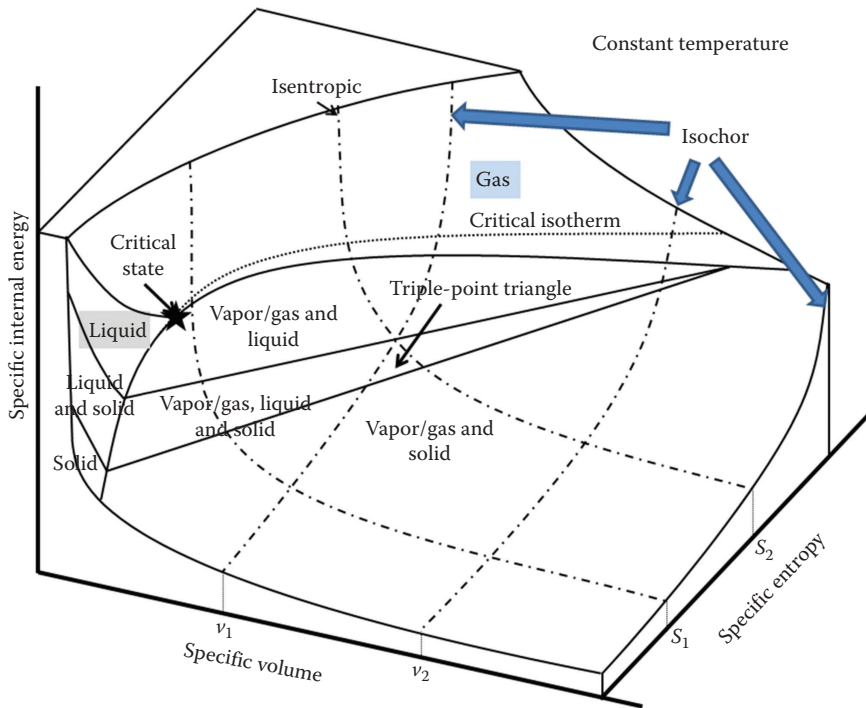


Figure I.36 Representation of the isochor in a fluid/solid system phase-diagram, indicating constant volume, in this case constant specific volume.

Isochoric process

[fluid dynamics, thermodynamics] Under the constraints of constant volume, the change in INTERNAL ENERGY (U) reduces to the temperature (T) multiplied by the change in entropy (S), which is the partial change in HEAT TRANSFER (Q): $dU = TdS = \delta Q^{\leftarrow}$. Alternatively, the change in internal energy for a system with constant constituents (n) is the heat capacity (c_v) multiplied by the change in temperature: $dU = (\partial U / \partial T)_{V,n} dT = c_v T$. The OTTO CYCLE has two segments that are isochoric, whereas the DIESEL CYCLE only has one out of four processes evolved under isochoric conditions, and the STERLING CYCLE has two stages of change that are isochoric.

Isolated system

[general, thermodynamics] A system that has no external ENERGY supplied or removed, hence the isolated system cannot influence the environment it is part of. An isolated system can only experience spontaneous changes of state.

Isomeric nuclei

[atomic] The isomeric model of the NUCLEUS is based on the BOHR MODEL, assuming a spherical shape. Based on the ENERGY, configuration of the sphere predictions can be made for the isomeric transitions (e.g., K-ISOMERISM) and the associated half-lives (τ_e and τ_m for electric and MAGNETIC transitions, respectively) as a function of the energy (E) released or introduced for the transition based on the mass number A , the MULTIPOLE order (ℓ_{multi}) and the occurrence of PARITY change (α_{parity}). The half-life is a function of the electric ("E") and magnetic ("M") reduced PROBABILITY defined as $B(E\ell_{\text{multi}})$ and $B(M\ell_{\text{multi}})$, yielding $[\tau_e(1+\alpha)]^{-1} = B(E\ell_{\text{multi}})E^{2\ell_{\text{multi}}+1}A^{2/3}$ and $[\tau_m(1+\alpha)]^{-1} = B(M\ell_{\text{multi}})E^{2\ell_{\text{multi}}+1}A^{(2\ell_{\text{multi}}-2)/3}$. The same model provides the means for defining the retardation in comparison with shell models through the introduction of the hindrance factor H_{isomeric} as $\log_{10}(H_{\text{isomeric}}) = 2(\Delta K_{\text{quant}} - \ell_{\text{multi}})$, where K_{quant} represents the QUANTUM number of nuclear SPIN along the axis of symmetry. The hindrance factor indicates the retardation in transition from a state with high spin (I) to GROUND STATE, which is indicated by the direction coinciding with the axis of symmetry as $K_{\text{quant}} = I$.

Isomers

[atomic, nuclear, solid-state] Two or more aggregates consisting of the same components that are arranged in different formats, with intrinsic different ENERGY, plural. Specifically, two nuclei of the same atomic species that persist in a different energy state, of which at least one energy state is metastable, are referred to as isomers (see Figure I.37).

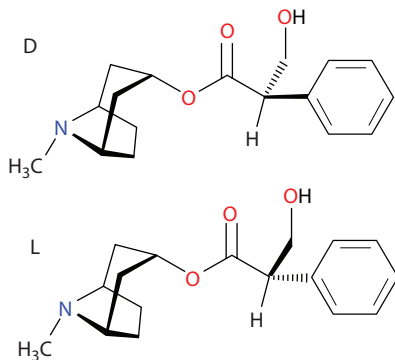


Figure I.37 Graphical representation of atropine L- and D-stereoisomer molecules.

Isometric

[biomedical, mechanics] Force applied by MUSCLE to compensate for external applied force, without a change in length (see Figure I.38).

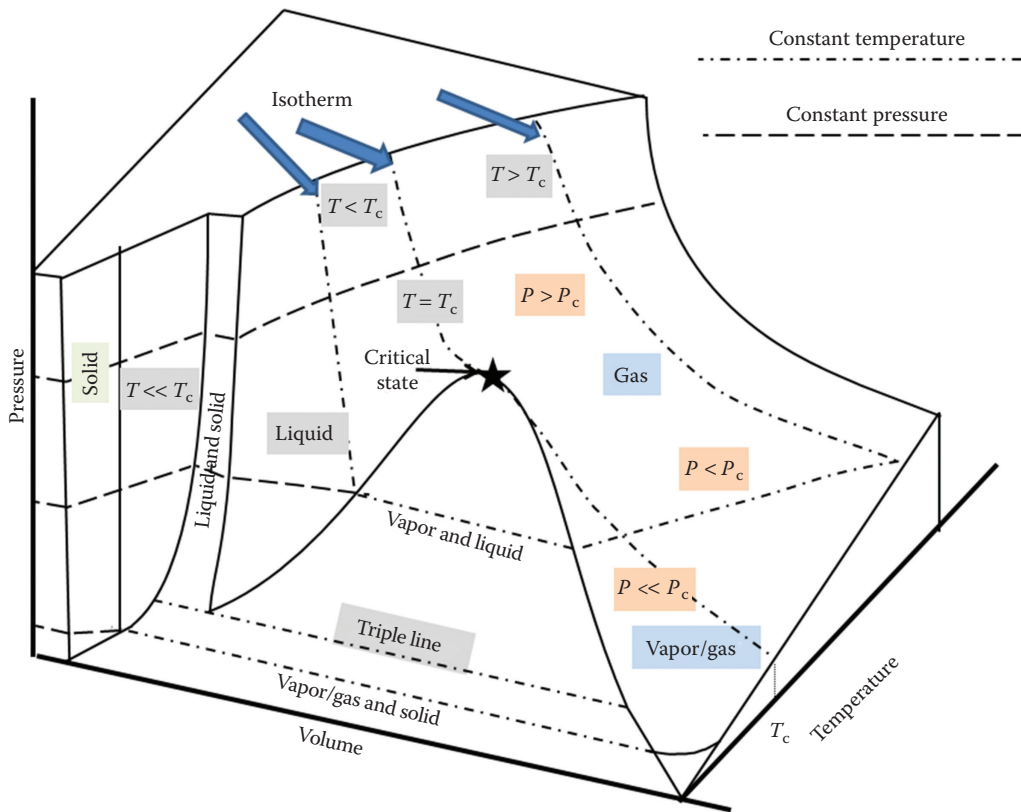


Figure I.38 Isothermal condition in a phase diagram of a system that has a linear relation between volume and temperature. This is in contrast to water, which has its highest density at 4°C.

Isospin (I)

[atomic, nuclear] System of particles, in particular hadrons, that interact on a NUCLEAR FORCE level which are in IDENTICAL STATES and have the same ordinary spin (J) and identical PARITY (π); generally, isospin multiplets are labeled J^π . The isospin is a dimensionless quantity (not specifically associated with an angular momentum) that describes the quantum number (I), which defines the conditions of the interactions in nuclear force; weak isospin refers to WEAK INTERACTION. Early references to the concepts

of isospin date back to the 1932 WERNER KARL HEISENBERG (1901–1976) considerations of the differences between the PROTON and NEUTRON in the NUCLEUS as two “identical” particles with different SPIN (and inherently different charges), which are affected equally by the nuclear force. The isospin also has an associated directional projection, which is the isospin vector squared (I_3). Theoretically, nuclear (strong) interactions of nuclides (e.g., BARYONS) are not affected by the direction of the isospin vector. It is also referred to as isotopic or isobaric spin. The isospin concept provided tools for the definition of quarks (*also see* YANG–MILLS THEORY).

Isotherm

[thermodynamics] A graphical representation of the locus of states in a system showing lines for processes that have the same temperature in a state diagram (pressure versus volume) or in a T – S diagram (temperature vs. entropy). Specifically, the phase changes of vaporization, SUBLIMATION, and SOLIDIFICATION/FUSION (respectively, their inverse processes) take place at constant temperature (see Figure I.39).

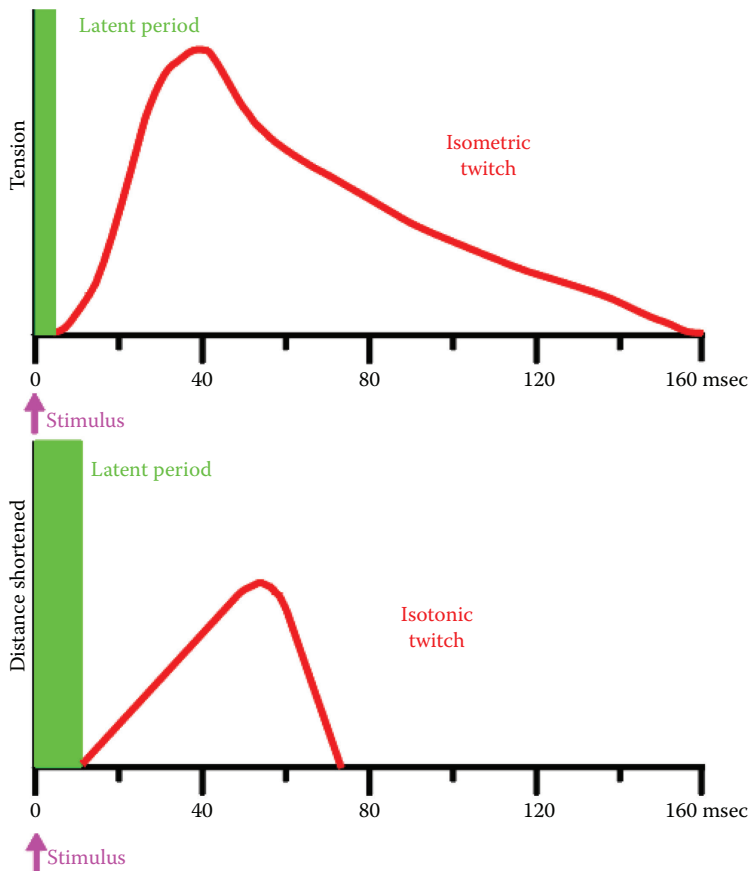


Figure I.39 Force diagram representing isometric muscle contraction.

Isothermal change

[general] A thermodynamic process that develops under constant temperature during at least one of the stages of a sequence of events. The STIRLING CYCLE has two phases that are isothermal, so does the LINDE–HAMPSON LIQUEFACTION CYCLE in refrigeration. The CARNOT CYCLE has two processes that are isothermal with respect to change in entropy.

Isotone

[atomic, nuclear] Two or more nuclides with the same number of neutrons (i.e., identical neutron number: A); however, the number of protons is different (i.e., different atomic number: Z), hence different mass number (A): $A = Z + N$. These isotones may also be isotopes with a limited lifetime. Examples of isotones are 36-sulfur, 37-chlorine, 38-argon, 39-potassium, and 40-calcium, each with 20 neutrons. The term was introduced in 1934 by the scientist Kurt Martin Guggenheimer (1902–1975) from Germany, based on the existing term ISOTOPE for equal number of protons. Guggenheimer realized that there had to be a third set of nuclear species, the NEUTRON, hence substituting the “n” for neutron in the definition of the existing definition for ISOBAR, indicated, respectively, with “p” for PROTON.

Isotonic

[biomedical] A MUSCLE contraction with constant force (see [Figure I.40](#)).



Figure I.40 Illustration of isotonic muscle contraction on left, whereas the muscle contraction applied to the weights on the right will most likely be a function of muscle contraction velocity.

Isotonic

[chemical] Two or more fluids with solutes that provide the same OSMOTIC PRESSURE. Generally, this consideration applies to solutions separated by a SEMIPERMEABLE MEMBRANE, such as the CELL wall in biological systems or artificial membranes in chemistry for PARTICLE separation. In biomedical use, the term “TONICITY” refers to the shape of a cell, which can be influenced by the internal pressure with respect to the extracellular FLUID composition (see [Figure I.41](#)).



Figure I.41 Infuse for delivery of isotonic fluids during surgery.

Isotope

[atomic, biomedical, imaging, nuclear] One of two or more forms of an ELEMENT having the same ATOMIC NUMBER (Z) (NUCLEAR CHARGE, representing the number of protons in the NUCLEUS) and hence occupying the same position in the periodic table. All isotopes are identical in chemical behavior, but are distinguishable by small differences in ATOMIC WEIGHT. The nuclei of all isotopes of a given element have the same number of protons but have different numbers of neutrons. The concept of isotopes was discovered by FREDERICK SODDY (1877–1956) in 1913 (see [Figure I.42](#)).

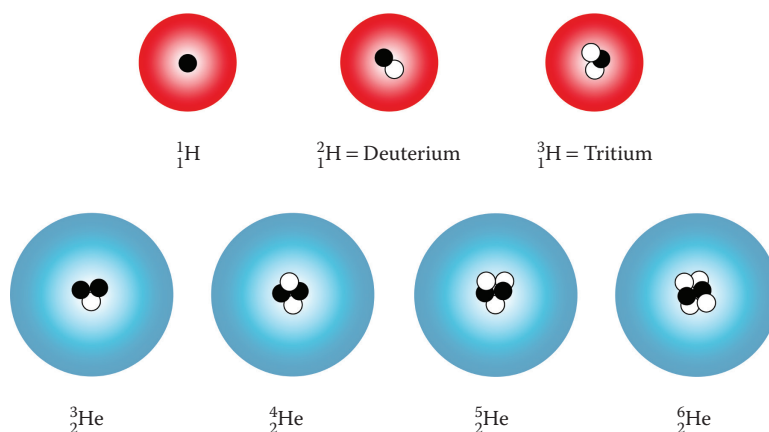


Figure I.42 Hydrogen and helium isotopes.

Jacobi, Carl Gustav Jacob (1804–1851)

[computational] A mathematician from the Prussian Empire, Germany. Jacobi's primary contributions in calculus-based PHYSICS are in the description of ellipsoids. Other work is in special solutions to complex integral equations. JACOBIAN calculus provides a range of SOLUTION mechanisms for various mathematical and practical problems. A specific area of interest is the Jacobi ellipsoids in techniques for solving complex problems (see [Figure J.1](#)).



Figure J.1 Carl Gustav Jacob Jacobi (1804–1851).

Jacobi method

[computational] A computational method based on an iteration process for solving a matrix equation with respect to a “reduced” pentadiagonal matrix (no zeros on its main diagonal). This defines the preferred algorithm for determining the solutions of a system of linear equations where the main diagonal in a matrix (M) representation contains the largest absolute values with respect to each row and column. The definition matrix is decomposed into a diagonal matrix (D) and the residue (R), which is a hollow matrix for a square matrix: $\mathbf{y} = [\mathbf{M}]\mathbf{x}$, where

$$[\mathbf{M}] = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} = [\mathbf{D}] + [\mathbf{R}] = \begin{bmatrix} a_{11} & \cdots & 0 \\ & a_{22} & 0 \\ \vdots & & \vdots \\ & 0 & \ddots \\ 0 & \cdots & a_{nn} \end{bmatrix} + \begin{bmatrix} 0 & \cdots & a_{1n} \\ & 0 & a_{2,n-1} \\ \vdots & & \ddots & \vdots \\ & a_{m-1,2} & 0 \\ a_{m1} & \cdots & 0 \end{bmatrix},$$

$$\mathbf{y} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}, \text{ and } \mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}.$$

The solutions for the functions can be found through iteration from $\mathbf{x}^{(\ell+1)} = [\mathbf{D}]^{-1}(\mathbf{y} - \mathbf{x}^{(\ell)})$.

Jacobi's ellipsoids

[computational, fluid dynamics] The Jacobi polynomials and ellipsoids are documented in great detail in M. Abramowitz (1915–1958) and I. A. Stegun's (1919–2008) *Handbook of Mathematical Functions*.

Jacobian

[computational, thermodynamics] In transformation ALGEBRA the POLAR COORDINATES are given as u, v and can be written as $u = v \cos \theta$ and $v = v \sin \theta$. To execute a coordinate transformation, the Jacobian is used and is given by

$$J = \begin{bmatrix} \frac{\partial u}{\partial v} & \frac{\partial u}{\partial \theta} \\ \frac{\partial v}{\partial v} & \frac{\partial v}{\partial \theta} \end{bmatrix} = \begin{bmatrix} \cos \theta & -v \sin \theta \\ \sin \theta & v \cos \theta \end{bmatrix} = v$$

Jahn–Teller effect

[general] The general tendency of a molecular system to become distorted under the influence of electronic DEGENERACY. Based on Coulombs' law, the electronic field effects and associated ENERGY are generally a linear function of DISTANCE within the molecular assembly. The elastic energy is proportional to the square of displacement. As a result, the displacement may lead to a reduction in energy of the system. In contrast, linear molecules such as CO₂ are not following the linear dependency to the displacement and hence may not be prone to distortion since the energy will not reduce. Photon resonant-electron absorption will generally be broadband based on the Jahn–Teller effect (i.e., dynamic Jahn–Teller effect), which may be subject to quenching due to spin-orbit coupling. The phenomenon was based on Landau's theoretical predictions in 1934 and postulated by HERMANN ARTHUR JAHN (1907–1979), a scientist from Great Britain, and Ede (Edward) Teller (1908–2003), a scientist from Hungary—also known as “the father of the HYDROGEN BOMB”—in 1936. The static Jahn–Teller effect explains the energy configuration that leads to crystal structures incorporation METAL ions.

Jakob number ($Ja = c_p(T_s - T_{\text{sat}})/\Delta H_{\text{vap}}$)

[thermodynamics] A dimensionless number expressing the ratio of heat or more generally the enthalpy change during a PHASE change to ENERGY of vaporization, specifically during the LIQUID to VAPOR or solid to liquid change in material phase (and vice versa), with c_p being the SPECIFIC HEAT under constant pressure, T_s the temperature of the liquid, T_{sat} the temperature of the ambient saturated vapor GAS PHASE (the temperature for a solid surface and liquid in contact, which may be best exemplified by dipping an ice-cream cone in a chocolate emulsion), and H_{vap} the LATENT HEAT of vaporization or more generally the heat required to initiate a phase change. Generally, the Jakob number is small, for instance during the transformation from water to ice: $Ja = 0.058$.

Jansen, Hans (early/mid-sixteenth century–early seventeenth century)

[optics] A scientist and optical engineer from the Netherlands. Working under the inspiration of his son ZACHARIAS JANSEN (1580–1640), they started making complex microscopes.

Jansen, Zacharias (1580–1640)

[optics] A scientist and engineer from the Netherlands. Zacharias Jansen was a spectacle maker by profession with an interest in producing complex devices for investigational purposes. He was part of the father-son team, which is the first known manufacturer of a compound microscope between 1590 and 1608. The MICROSCOPE had a power of approximately nine times magnification ($9\times$), and later model up to $30\times$. The father HANS JANSEN (early/mid sixteenth century–early seventeenth century) contributed equally. The microscope was later refined by HANS LIPPERSHEY (1570–1619) around 1608. He is also found as Zacherias Janssen and Zacharias Janssen (see [Figure J.2](#)).



Figure J.2 Zacharias Jansen (1580–1640).

Jefimenko, Oleg Dmitrovich (1922–2009)

[computational] A mathematician and scientist from the Ukraine. Oleg Jefimenko is known for his contributions to ELECTRICITY and MAGNETISM, specifically under special relativity terms. Additional work of Oleg Jefimenko was in designing electromotor (see [Figure J.3](#)).

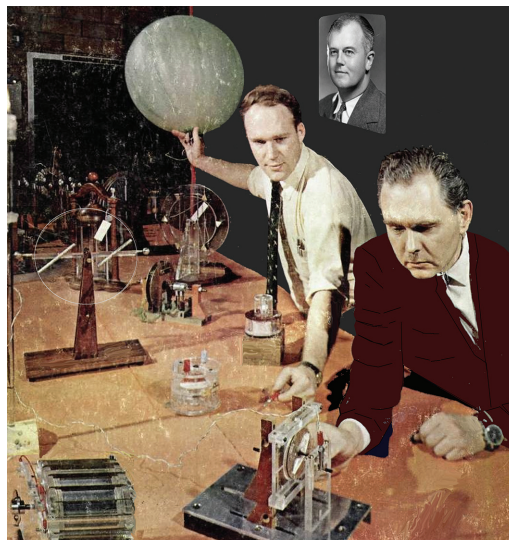


Figure J.3 Oleg Dmitrovich Jefimenko (right) (1922–2009).

Jefimenko's equations

[computational, electromagnetism] Equations describing electric and MAGNETIC FIELD behavior based on charge distribution (charge density: $\rho_e[3-D]$) and/or current density (J_e) distribution with respect to time retardation: $t_r = t - [(\vec{r} - \vec{r}')/c]$, where $c = 2.99792458 \times 10^8$ m/s the speed of light, all with respect to location $\vec{r}$, and $\vec{r}'$ location in the charge distribution. The concept was introduced by OLEG DMITROVICH JEFIMENKO (1922–2009). The electric field is derived from:

$$\vec{E}(\vec{r}, t) = (1/4\pi\epsilon_0) \int \left\{ \left[\rho_e(\vec{r}', t_r) / |\vec{r} - \vec{r}'|^3 \right] + \left[(1/|\vec{r} - \vec{r}'|^2 c) \left[\partial \rho_e(\vec{r}', t_r) / \partial t \right] \right] \right\} [\vec{r} - \vec{r}'] - \left[(1/|\vec{r} - \vec{r}'|^2 c) \left(\partial \vec{J}(\vec{r}', t_r) / \partial t \right) \right] d^3 \vec{r}',$$

where $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space. Note the resemblance to the Coulomb expression. The magnetic field follows from

$$\vec{B}(\vec{r}, t) = \mu_0/4\pi \int \left\{ \left[\vec{J}(\vec{r}', t_r) / |\vec{r} - \vec{r}'|^3 \right] + \left(1/|\vec{r} - \vec{r}'|^2 c \right) \left[\partial \vec{J}(\vec{r}', t_r) / \partial t \right] \right\} [(\vec{r} - \vec{r}') \times (\vec{r} - \vec{r}')] d^3 \vec{r}',$$

with $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$, the permeability of free space.

Jensen, Johannes Hans Daniel (1907–1973)

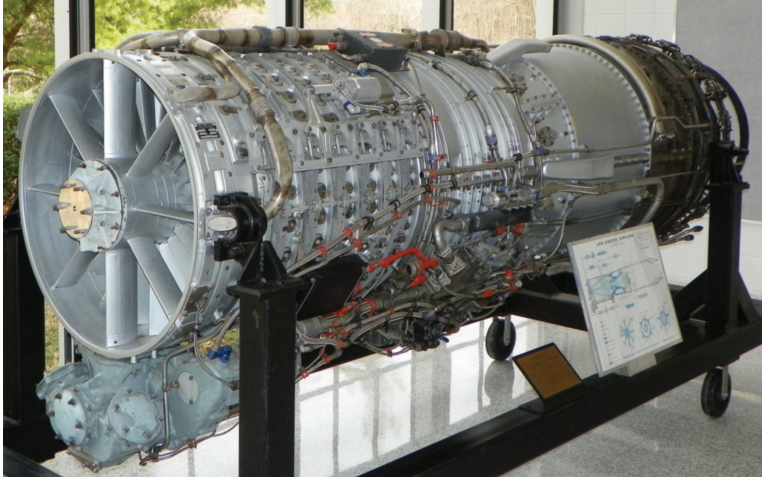
[general, nuclear] A physicist from Germany who worked on nuclear ENERGY generation and the production of uranium isotopes. Jensen also illustrated that the number of states in the shells of the BOHR ATOMIC MODEL are equivalent to the MAGNETIC quantum numbers. Johannes Jensen received the Nobel Prize in Physics in 1963 for his work on the definition of the atomic nuclear SHELL MODEL defined in 1949, which he shared with MARIA GOEPPERT-MAYER (1906–1972) and EUGENE WIGNER (1902–1995) (see [Figure J.4](#)).



Figure J.4 Johannes Hans Daniel Jensen (1907–1973).

Jet

[fluid dynamics] The forceful projection of a LIQUID or GAS PHASE from a narrow ORIFICE: NOZZLE. It is also used to describe an ENGINE used for PROPULSION, known as jet engine. Similarly, it is used to describe the airplane that uses the jet engine as a propellant mechanism. Liquid jets are used in propulsion for water crafts (e.g., water scooter) and also to cut materials (see [Figure J.5](#)).



(a)



(b)

Figure J.5 (a) Jet engine and (b) water jet cutting steel.

Jet force

[fluid dynamics] Newton's third law force: "for every action there is an equal and opposite reaction" resulting from the excretion of a MASS (m) of GAS or LIQUID, the forces ($\vec{F}$) are in all directions, with only one WALL that can be displaced under the influence of the release, hence moving this wall in the opposite direction of the ejected FLUID. The MOTION can be approximated using the LAW OF CONSERVATION OF MOMENTUM ($p = mv$) yielding $F = dp/dt = d(mv)/dt$, when neglecting FRICTION and thermal effects, while considering the DENSITY (ρ) and surface area (A) involved for the mass aspect, and the average FLOW velocity is $\vec{v}$, when applied in a single direction: $\sum F_x = \int \rho v_x (\vec{v} \cdot \vec{n}) dA$.

Jet plane

[fluid dynamics] Airplane propelled by TURBINE jet ENGINE, using the combustion as the propellant, in contrast to a PROPELLER plane (see [Figure J.6](#)).



Figure J.6 US Air force Thunderbirds fighter jets in air show.

Jet theory for capillary phenomena

[fluid dynamics] The pressure at the NOZZLE of a JET is $P = (T_s/R) + \text{Const}$, where T_s is the SURFACE TENSION of the FLUID and R is the radius of the ORIFICE. The emerging jet from the nozzle will have a WAVE phenomenon, resulting from edge effects and subsequent INTERFERENCE. The VIBRATION modes (n) are a direct function of the surface tension and inversely proportional to the average radius of the orifice cubed as $v_{\text{vib}} = \sqrt{\frac{4}{3}(n+1)(n-1)(n+2)(T_s / \rho' R^3)}}$, with respect to density ρ' (see [Figure J.7](#)).



Figure J.7 Wave effect at a nozzle that is generating a water-jet.

J-fet

[electronics] Junction gate field-effect transistor. This type of field effect transistors uses a voltage controlled gate for regulation of RESISTANCE in an amplifier circuit. This design provides the most simple transistor mechanism. The voltage applied to the base of the TRANSISTOR controls the gate current. The applied voltage modulates the DEPLETION LAYER in the npn or pnp semiconductor configuration.

j-j coupling

[atomic, solid-state] ELECTRON SPIN coupling based on the angular momentum: $\vec{J} = \vec{L} + \vec{S}$, where $\vec{L} = \sum_i \vec{L}_i$ the total ORBITAL ANGULAR MOMENTUM, with on-axis component $L_z = m\hbar$, where m represents the momentum quantum number and $\hbar = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ Planck's constant, $\hbar = h/2\pi$ and $\vec{S} = \sum_i \vec{S}_i$ the SPIN momentum. The total kinetic ENERGY with respect to the atomic state is defined by $\vec{J} = \sum_i \vec{L}_i$ with respect to the sum of the kinetic moment of the i th electron in orbit for the ATOM. The j-j coupling (jj-coupling) accounts for the atomic kinetic energy configuration for heavy atoms, whereas Russel–Saunders, or L–S COUPLING, describes the energy configuration primarily pertaining to light atoms. The electron condition is confined by the sum of the kinetic (E_k) and potential energy ($V(r)$), defined through the HAMILTONIAN OPERATOR (H) for the VALENCE electrons as $H = E_k + V(r) + H_{ee} + H_{ss} + H_{sl}$, with H_{ee} being the electrostatic interaction for the external electrons, H_{ss} the spin–spin interaction—Hamiltonian, and H_{sl} the spin–orbital interaction under the boundary conditions: $H_{sl} \ll H_{ee}$ and $H_{sl} \ll H_{ss}$ (see Figure J.8).

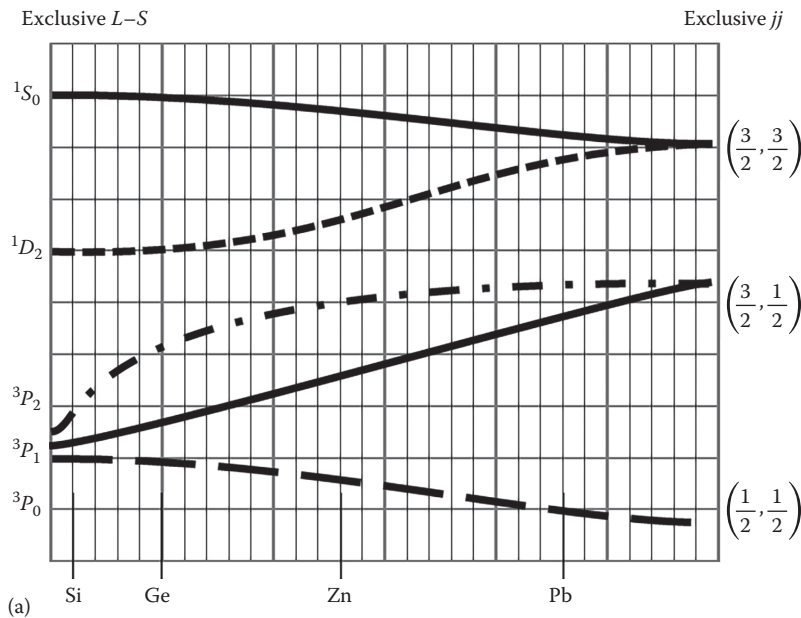


Figure J.8 (a) Correlation between L–S–j–j coupling for elements in the fourth main group of the periodic table: Silicon (Si); Germanium (Ge); Zinc (Zn); and Lead (Pb). (Continued)

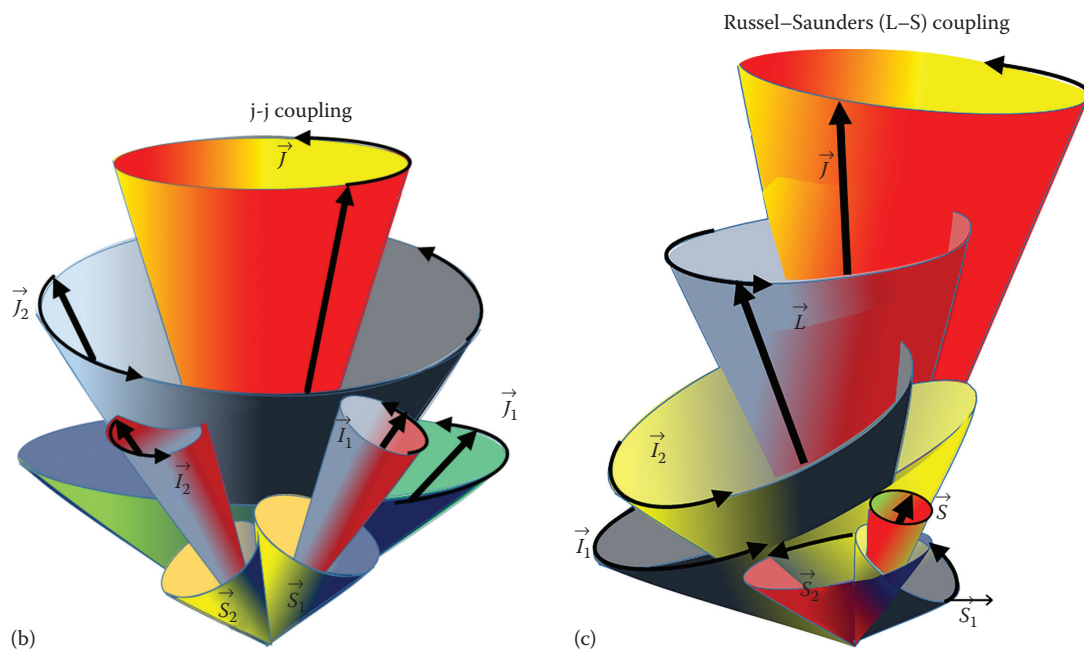


Figure J.8 (Continued) (b) illustration of j-j coupling (c) illustration of L-S Coupling (Russel-Saunders).

Johnson noise

[atomic, electromagnetism, nuclear] Thermal NOISE in signals resulting from random electron movement.

Joint reaction force

[biomedical] Inertial force between two adjacent bones in a flexing joint, such as a knee, wrist, or shoulder.

Joint strength

[acoustics, mechanics] Bond strength between two formations. Quantifiable measure for nondestructive testing using ULTRASOUND, based on the derived local elastic modulus.

Joints

[biomedical] Flexible structure merging two or more bone structures held together by collagen strands (e.g., tendons), often cushioned by a collagen disk placed between the pivoting bone structure (see [Figure J.9](#)).



Figure J.9 Person running with several anatomical joints highlighted and a close-up of the joint at the knee of the leg with the meniscus “friction-plate.”

Joliot (Joliot-Curie), Jean Frédéric (1900–1958)

[general, nuclear] A scientist from France, and husband of IRÈNE JOLIOT-CURIE (1897–1956). Their work led to the formation of several long-time stable radioisotopes (long in the range of minutes, not nanoseconds).

Joliot-Curie, Irène (1897–1956)

[general] A scientist from France, daughter of MARIE (MANYA) SKLODOVSKA CURIE (1867–1934) and PIERRE CURIE (1859–1906), and husband to JEAN FRÉDÉRIC JOLIOT-CURIE (1900–1958). The husband and wife team received the Nobel Prize in Chemistry for their work on the bombardment of light metals with alpha

particles and hence managed to generate phosphor out of aluminum. The phosphor remained artificially radioactive for a considerable time, emitting positrons and reducing to silicon (see [Figure J.10](#)).

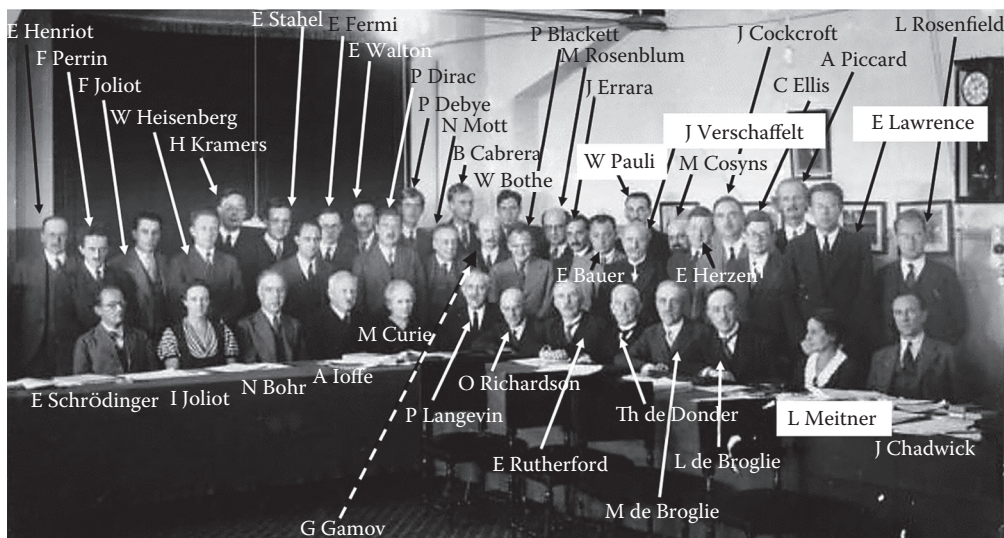


Figure J.10 Irène Joliot-Curie [Irène Joliot] (1897–1956) at the 1933 Solway conference seated between Erwin Schrödinger (1887–1961) and Niels Henrik David Bohr (1885–1962) on the front left. Behind her stands her husband Jean Frédéric Joliot (1900–1958).

Josephson, Brian David (1940–)

[condensed matter, solid-state] A physicist from Great Britain. Johnson worked on SUPERCONDUCTIVITY, specifically pertaining to the QUANTUM effects of solids. Johnson received the Nobel Prize in Physics in 1973 for his description of the “TUNNELING” effect resulting in superconductivity, outlined in 1962 (*also see JOSEPHSON EFFECT*) (see [Figure J.11](#)).



Figure J.11 Brian David Josephson (1940–).

Josephson effects

[condensed matter, electronics, solid-state] Superconductivity resulting from COOPER PAIRS, resulting in a supercurrent crossing an interface between two superconductors made up from a thin conducting or insulating barrier (JOSEPHSON SUPERCONDUCTING JUNCTION), named after the work of BRIAN DAVID JOSEPHSON (1940–) released in 1962. The supercurrent will prevail as long as the current remains below a certain threshold value. As a result of a VOLTAGE (V) across the span an “alternating current” will result, with a frequency $\nu = 2e(V/\hbar)$, and an alternating phase difference ($\Delta\phi$) that applies to the pair phase between the two respective superconductors as $(\partial/\partial t) \Delta\phi = 2e(V/\hbar)$, where e is the electron charge and $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$. Planck's constant, and t is time. In case the POTENTIAL DIFFERENCE is constant, the PHASE difference will gradually increase as $\Delta\phi(t) = 2e(V_0 t/\hbar) + \Delta\phi(0)$. The Johnson effect support high-speed switches for supercomputers and can form a standard to measure fundamental constants. When an (additional) alternating potential (V_1) is applied the junction CURRENT (I) becomes $I = I_0 \sin(2e(V_0 t/\hbar) + 2e(V_1 t/\hbar\omega) \sin(\omega t) + \Delta\phi(0))$, where ω is the modulation frequency (primarily in the radio-frequency range).

Josephson superconducting junction

[condensed matter, electronics, solid-state] BARRIER between two superconductors that may act as a superconductor, while in fact consisting of a material that has low conductivity or even an INSULATOR, but only a thin film (see [Figure J.12](#)).

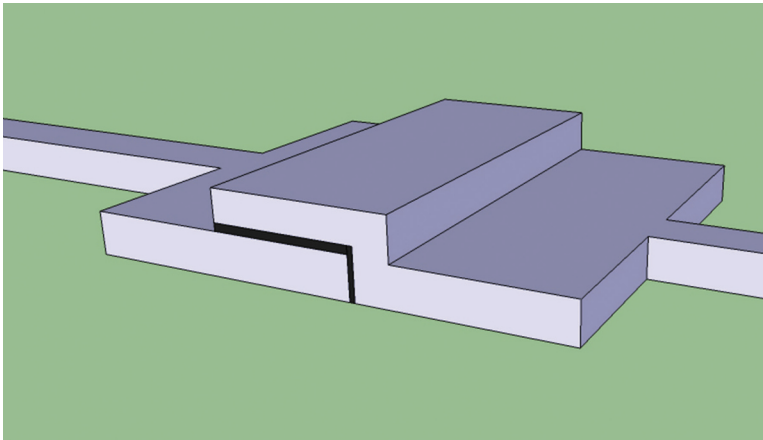


Figure J.12 Illustration of the Josephson superconducting junction.

Jost function

[computational, mechanics, solid-state] Scattering function that defines the collision PROBABILITY and related processes as a tool for solving the SCHRÖDINGER EQUATION in nonrelativistic interaction of acoustic imaging as well as PARTICLE interaction, for example, electron microscopy. The Jost function applies in particular to the time-independent Schrödinger equation. Introduced by Res Jost (1918–1990), theoretical physicist from Switzerland.

Joukowski's hypothesis

[fluid dynamics] In AERODYNAMICS this describes the conditions forming a CIRCULATION in flow, specifically around the WING of a plane. The phenomenon pertains to the LIFT of an AIRFOIL. Generally, the FLOW is prevented from passing the trailing edge of the “rear stagnation point,” as identified in cross-sectional view. In case the flow reaching the tip of the wing approaches at an ANGLE with the axis of the airfoil that is not too large, the circulation will adjust itself to compensate for this “break-off” point. This captures the principles of Joukowski's hypothesis. See KUTTA–JOUKOWSKI HYPOTHESIS, named after NIKOLAI ZHUKOVSKY JOUKOWSKI (1847–1921) and (1867–1944). Also see KUTTA CONDITION.

Joukowsky, Nikolay (1847–1921)

[computational, fluid dynamics] See **ZHUKOVSKY, NIKOLAY**.

Joukowsky equation

[fluid dynamics] Describing the pressure change resulting from a sudden change in FLOW velocity of a fluid ELEMENT due to a blockage, narrowing, curve or other restriction based on Newton's laws of MOTION combined with the EQUATION OF CONTINUITY yields the expression: $\delta P / \delta t = \rho a (\delta v / \delta t)$, with P being the PRESSURE (in pascal), v the flow velocity, t the time, and $a = \sqrt{(K/\rho) / [1 + (D/b)(K/E)\text{Const}]}$ the free-flow velocity in a flexible tube with the LIQUID flow density ρ . Based on the work of NIKOLAY JOUKOWSKY (NIKOLAY ZHUKOVSKY) (1847–1921).

Joule, James Prescott (1818–1889)

[general, thermodynamics] A scientist from Great Britain, best known for his quest to find the common-denominator linking work to ENERGY and heat. The SI unit for energy is named after him ([J], joule). One specific topic of his work was in the heat generated by the current FLOW through a RESISTOR (i.e., JOULE HEAT) (see [Figure J.13](#)).



Figure J.13 James Prescott Joule (1818–1889).

Joule (J)

[general, thermodynamics] A unit of work or ENERGY, mechanical equivalent of heat. This concept and unit was named after the pioneering work by JAMES PRESCOTT JOULE (1818–1889). This relates to the other unit in heat (calorie) as $4.186 \text{ J} = 1 \text{ cal}$.

Joule heat

[general, thermodynamics] The power (P_E) generation (alternatively: power dissipation) resulting from a CURRENT (I) through a RESISTOR (R) under an applied VOLTAGE (V) expressed by JAMES PRESCOTT JOULE (1818–1889) as $P_E = I^2 R = V^2/R$ in 1841 (“heating power”). The THERMAL ENERGY produced in this manner is referred to as “joule heat.”

Joule law

[general, thermodynamics] The HEAT (Q) generated from a CURRENT (I) through a RESISTOR (R) under the influence of an applied voltage (V): $Q = I^2 R t = (V^2/R)t$, where t is the time duration for the event.

Joule–Brayton cycle

[thermodynamics] Cyclic GAS compression/EXPANSION process consisting of two ISENTROPIC (i.e., constant entropy) and two isobaric components (i.e., constant pressure). This mechanism applies to certain gas-turbine ENERGY conversion processes, specifically for AIR compression. The efficiency of the Joule–Brayton cycle ENGINE is a direct function of the pressure ratio in the upper and lower portion of the cycle in a reversible process. This falls in the same category as the STIRLING CYCLE (see [Figure J.14](#)).

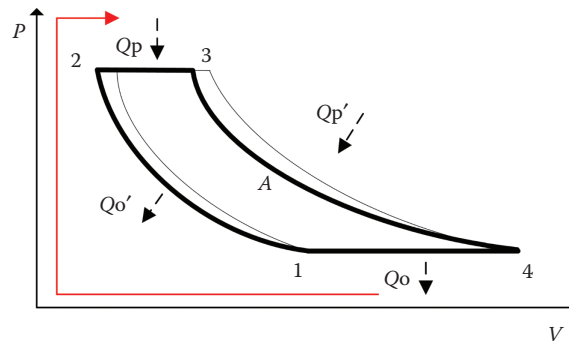


Figure J.14 Diagram of the mechanical processes in the Joule–Brayton cycle.

Joule–Kelvin effect

[thermodynamics] When a GAS expands while exiting from a porous plug or ORIFICE, it may reduce or increase in temperature. The temperature change will depend on the specific isenthalp for the gas. Temperatures will rise on EXPANSION on one side (right side) of the isenthalp, whereas the gas temperature will decrease on the opposite side (*also* JOULE–THOMPSON EFFECT) (see Figure J.15).

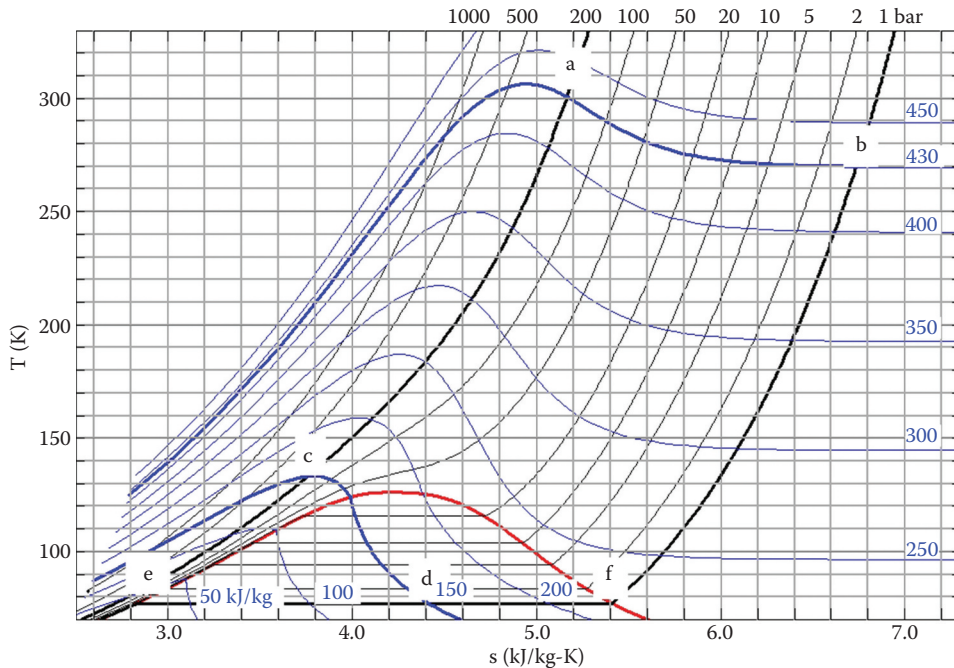


Figure J.15 Joule–Kelvin effect for nitrogen T-s diagram of nitrogen. The red dome represents the two-phase region with the low-entropy side (the saturated liquid) and the high-entropy side (the saturated gas). The black curves give the T-s relation along isobars. The pressures are indicated in bar. The blue curves are isenthalps (curves of constant specific enthalpy). The specific enthalpies are indicated in kJ/kg. The specific points a, b, and so on are treated in the main text. (Data from [http://en.wikipedia.org/wiki/Joule–Thomson_effect#Throttling in the Ts diagram of nitrogen](http://en.wikipedia.org/wiki/Joule–Thomson_effect#Throttling_in_the_Ts_diagram_of_nitrogen). [http://en.wikipedia.org/wiki/Joule–Thomson_effect#mediaviewer/File:Throttling in Ts diagram_01.jpg](http://en.wikipedia.org/wiki/Joule–Thomson_effect#mediaviewer/File:Throttling_in_Ts_diagram_01.jpg).)

Joule–Thomson coefficient

[thermodynamics] Partial derivative of temperature (T) against PRESSURE (P) in an expansion/compression scheme: $(\partial T / \partial P)_h = (V / c_p)(T \alpha_p - 1)$, where α_p is the coefficient of isobaric expansion, c_p is the SPECIFIC HEAT of the medium under constant pressure (which follows from the EQUATION OF STATE), V is the volume, and h is the LATENT HEAT of the vapor-liquid equilibrium. Note that the EXPANSION is a nonreversible, but frequently it is an ADIABATIC PROCESS. This phenomenon can accompany a rapid expansion followed by crystallization of the emerging gas, for example, carbon dioxide from a fire extinguisher. When the GAS is above the INVERSION temperature before expansion the Joule–Thomson coefficient is negative and the gas will increase in

temperature on expansion, while when it is below the inversion temperature it will cool, because the Joule–Thomson coefficient is positive. Note that the change in pressure is always negative on expansion (see Figure J.16).

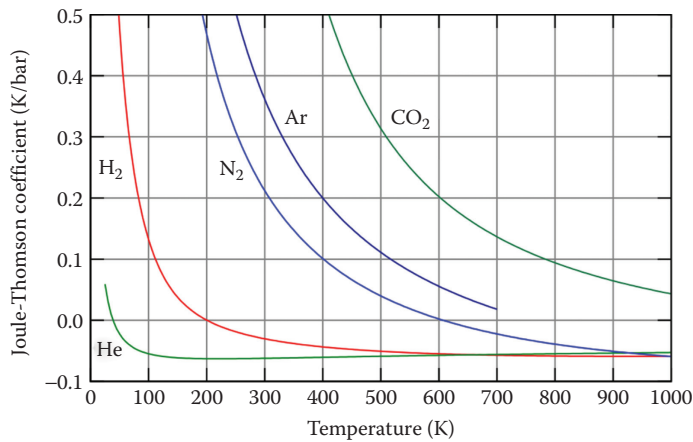


Figure J.16 Joule–Thomson coefficient for several gases as a function of temperature. (Data from http://en.wikipedia.org/wiki/File:Joule-Thomson_curves_2.svg.)

Joule–Thomson effect

[thermodynamics] The nontemperature effects resulting from a rapid EXPANSION of a GAS from a porous stopper or NOZZLE. In most cases, the expansion is adiabatic. In case the expansion is ISENTROPIC, it will be reversible and positive work that is performed. On the other hand, the process may be free expansion and will be irreversible. The (specific) enthalpy in this case remains constant, no change in kinetic ENERGY (i.e., constant temperature). The Joule–Thomson effect will occur for most ideal gases, with the exception of helium, hydrogen, and neon gases on expansion; these three gases cool on expansion. This effect was discovered by JAMES PRESCOTT JOULE (1818–1889) and WILLIAM THOMPSON (1824–1907) (i.e., Lord Kelvin) in 1852 (*also see* JOULE–KELVIN EFFECT *and* JOULE–THOMSON COEFFICIENT).

Journal bearing

[fluid dynamics] Shaft (also referred to as “journal”) that rotates in a METAL sleeve under tight tolerance, for instance, used in supporting the crank-shaft of automobile and motorcycle engines. In comparison, the majority of bearings only have rolling RESISTANCE, relying on balls or tubs rolling in two close-fit opposite grooves. The FRICTION in this close metal-to-metal contact and sliding lubrication is usually provided by forced injection of lubricant ([semi-]lubricated bearing) or by means of a low-friction sleeve insert made out of PTFE, teflon, or NYLON (i.e., “dry-journal bearing”). The theory of lubrication for journal bearings uses an intricate FLUID DYNAMICS approach. The OIL in a lubricated bearing will tend to “accumulate” in the direction of MOTION, causing a pressure gradient in the lubricant that is antiparallel to the direction of motion. Because of the tight tolerances, the gap in the journal bearing spacing is narrow, but finite and the shaft will be able to move radially and place the shaft in an eccentric position. The highest pressure is at the rear side of the point of contact from the direction of motion. A special phenomenon is “oil-whirl.” Pressures in

journal bearings can exceed 40 MPa. A related example of the “LUBRICATION” process for a journal bearing is experienced during hydroplaning of an automobile tire (see Figure J.17).

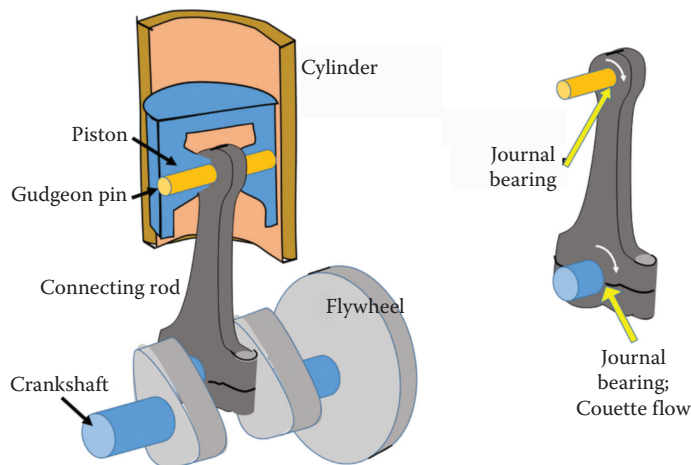


Figure J.17 Journal bearing.

Junction diode

[electronics, general] *pn*-junction with DEPLETION LAYER sandwiched between acting as a current controlled INSULATOR, where the depletion layer is deprived of charges and acts as a CAPACITOR. The *p* material (e.g., single crystalline *p*-type GALLIUM-doped silicon) has an effective POSITIVE CHARGE due to lack of electrons and the *n* semiconductor (e.g., *n*-type Arsenic-doped silicon) is negatively charged due to an excess of electrons (gallium-arsenide DIODE, GaAs) (see Figure J.18).

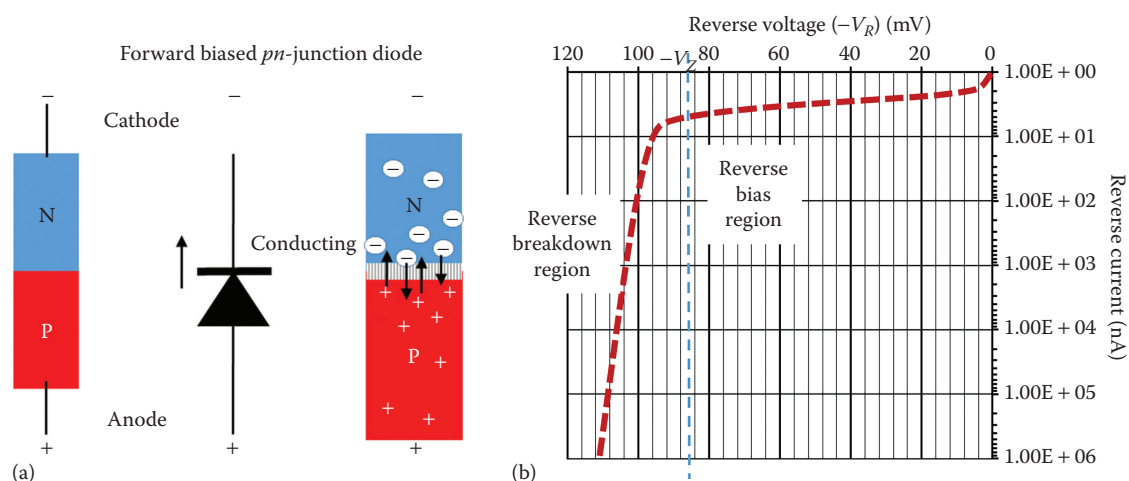


Figure J.18 (a,b) Junction diode.

Junction rule

[electronics] In a circuit at any junction (connection point of two or more “wires”), the sum of all the currents will be zero, where FLOW to the junction is positive and away is represented as negative (also **KIRCHHOFF’S FIRST RULE**).

Junction transistor

[electronics, general, solid-state] A **TRANSISTOR** consisting of two pairs of *pn*-junctions, which are in tight proximity for current control. The respective *pn*-junctions are in close proximity. The one *pn*-JUNCTION will serve as forward-biased emitter, whereas the second forms the reverse-biased collector. One junction forms the forward-biased emitter, whereas the other is configured as a reverse-biased collector. The transistor is nonoperational when the transistor is powered in a way where the collector and emitter are both reverse biased. When both the collector and emitter are reverse-biased, the transistor is switched off. The first junction transistor was developed in 1949 by William Shockley (1910–1989) at Bell Laboratories, Murray Hill, New Jersey (see [Figure J.19](#)).

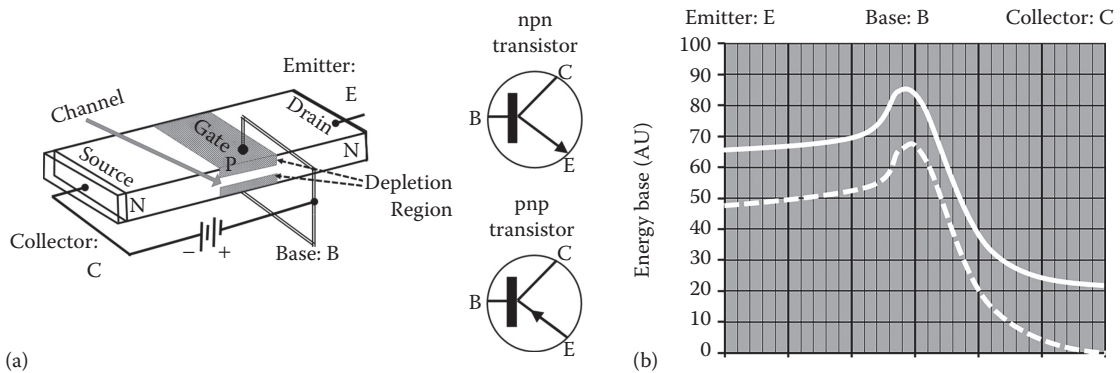


Figure J.19 (a,b) Junction transistor.

Junge power law

[chemistry, energy, fluid-dynamics, molecular, solid-state] An expression for the size distribution function of **AEROSOL** particles in suspension, defined as $dn/d \log r = c_{\text{const}} r^{-b}$, where r is the **PARTICLE** radius, dn the segment of particles within a specific logarithmic size range, $b \sim 3$ a parameter which usually can be taken as 3, and c_{const} a constant that depends on the boundary conditions such as source, relative **HUMIDITY**, and **SATURATION**. Generally, the particle distribution peaks between $0.1 \mu\text{m}$ and $20 \mu\text{m}$. Frequently, a **NORMAL DISTRIBUTION** is assumed for the size. Sources may include smoke produced by combustion and dust or pollen. The concept was introduced by Christian Junge (1912–1996) in 1969. He was one of the first researchers who performed a

systematic and detailed analysis of the chemical composition of atmospheric aerosols and their respective size/volume distribution between 1953 and 1963 (see Figure J.20).

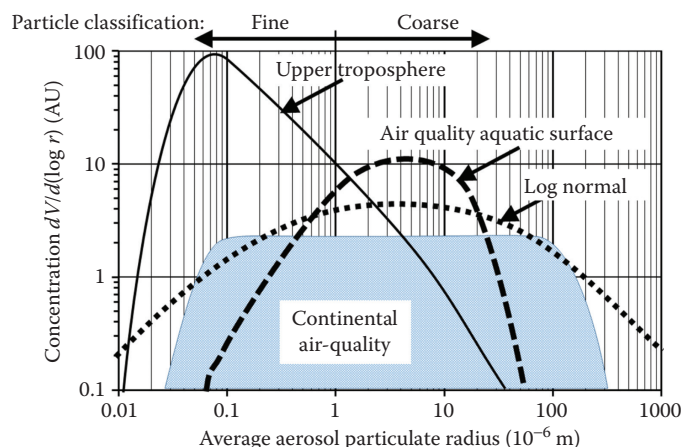


Figure J.20 Outline of the volume distribution for several atmospheric aerosols as described by Christian Junge (1912–1996) in 1969; the Junge power law. (Data from <http://www.iara.org/newsfolder/pioneers/6AerosolPioneerEditedAugJunge.pdf>.)

Jupiter

[astrophysics/astronomy, general] It is the fifth PLANET away from the Sun. Jupiter has one moon: Io. Jupiter is called a GAS giant, and the flowing GAS has an unstable turbulent VORTEX (anticyclonic storm), known as the “Great Red Spot,” which has been reducing in size over the observation time. Jupiter does not have a MESOSPHERE, that is, no solid core. The revolution around the Sun measured in EARTH time is 11.8618 year, whereas in Jupiter days it is 10,475.8 Jupiter days. The radius at the equator is $71,492 \pm 4$ km, which is 11.209 times the radius of the Earth at the equator (see Figure J.21).

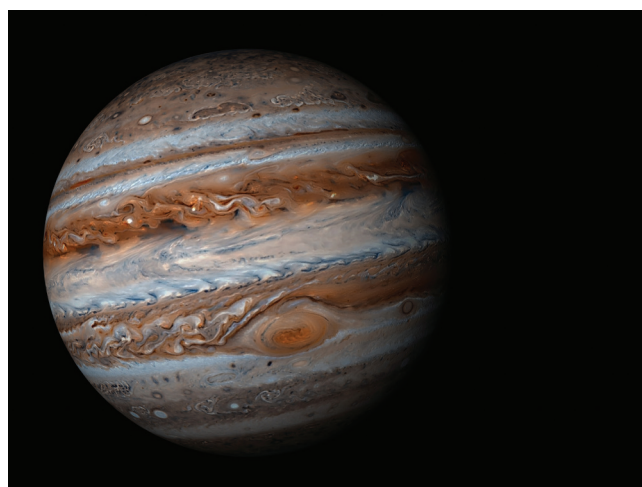


Figure J.21 Jupiter.

K

K characteristic X-rays

[atomic, electromagnetism, nuclear] See **X-RAY**.

K meson

[atomic, nuclear] Unstable zero-spin mesons that DECAY into ION pairs; also referred to as “K-ons”: kaons. The kaons with zero SPIN are K^+ , $\bar{K}^-$, K^0 , and its respective anti-particle $\bar{K}^0$, with respective decay PION components: $K^0 \rightarrow \pi^+ + \pi^-$; $\bar{K}^0 \rightarrow \pi^0 + \pi^0$; $\bar{K}^+ \rightarrow \pi^+ + \pi^0$ (where the pions decay into leptons or phonons: $\pi^+ \rightarrow \mu^+ + \nu_\mu$, respectively $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$). The mesons were always produced in pairs: K^0 and the LAMBDA PARTICLE Λ^0 , called “strange particles,” due to their relatively long decay time in the order of nanoseconds. The KAON K^0 and K^+ has a strangeness +1, whereas the counterpart BARYON Λ^0 has a strangeness -1.

K Series

[nuclear] See **K-ALPHA LINES**.

K-alpha lines

[atomic, energy, nuclear] Characteristic emissions spectral lines. Emission lines resulting from the excitation of the *k*-shell electrons: 2p orbit. *K*-lines are X-RAY emissions. The DECAY is predominantly between the $2p_{3/2}$ (at 933 eV) and $2p_{1/2}$ (at 952 eV) to the $1s_{1/2}$ ENERGY level at 8979 eV. In contrast to the *K*-beta line which is associated with the transition between 3p at 76 eV to 1s. The emission lines are doublets (two closely separated lines that may not always be resolved) with the highest known energy, labeled as $K\alpha_1$ and $K\alpha_2$, where $\Delta E_{\alpha_1} > \Delta E_{\alpha_2}$. For instance, for copper $K\alpha = 1.54184 \text{ \AA}$ (split: $K\alpha_1 = 1.54056 \text{ \AA}$ and $\alpha_2 = 1.54439 \text{ \AA}$), and for another popular ANODE material in X-ray sources, molybdenum $K\alpha = 0.71073 \text{ \AA}$ (see [Figure K.1](#)).

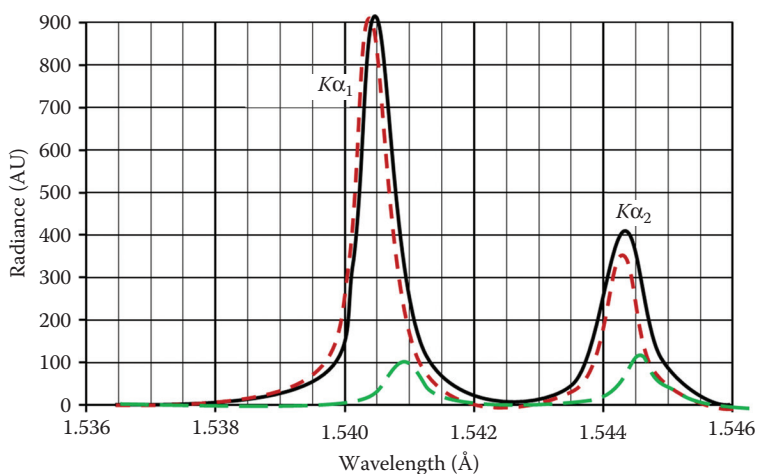


Figure K.1 K-alpha line spectrum for copper (Cu).

K-electron capture

[atomic, nuclear] Radioactive decay involving the capture of high ENERGY *K*-shell electrons by the NUCLEUS of the ATOM. During this charge integration, protons convert into NEUTRON and the nuclide decreases in atomic number, while an electron NEUTRINO is emitted. Examples include the conversion of aluminum to magnesium ($^{26}_{13}\text{Al} + e^- \rightarrow ^{26}_{12}\text{Mg} + \nu_e$) and potassium to argon ($^{40}_{19}\text{K} + e^- \rightarrow ^{40}_{18}\text{Ar} + \nu_e$).

k-Epsilon model

[computational, fluid dynamics] Mathematical and computational model for turbulent FLOW calculations using two sets of transport equations. The first set of equation is the transport of kinetic ENERGY within the turbulent flow, and the second set represents the turbulent dissipation, that is, the MAGNITUDE of TURBULENCE. When the pressure gradients become too large the model will result in errors and deviations (*also k-e MODEL*).

K-isomerism

[nuclear] Nuclear transitions in reference to the QUANTUM NUMBER “ K_{quant} ,” which denotes the component of the nuclear SPIN along the rotational axis of symmetry. The GROUND STATE of a deformed NUCLEUS with even–even configuration (i.e., $Z = \text{even}$, where Z defines the atomic number designating the number of protons in the nucleus, and $N = \text{even}$ represent the number of neutrons; examples are URANIUM (^{238}U) and protactinium (^{234}Pa). (Note: $Z + N = A$, with A the mass number of the ATOM.) For specific even–even nuclei the condition applies $K_{\text{quant}}^{\pi} = 0^{+}$ for the rotational band with respect to *K*-isomerism. *K*-isomeric transitions are mainly between states indicated by multipolarity states: $E1$, $M1$, and $M2$. The multipolarity transition states are associated with the corresponding electric (“ E ”) and MAGNETIC (“ M ”) reduced PROBABILITY defined as $B(E\ell_{\text{multi}})$ and $B(M\ell_{\text{multi}})$, where ℓ_{multi} is the MULTIPOLE order. In *K*-isomerism mainly the $E1$, $M1$, and $M2$ transitions are retarded for the isomeric nucleus with respective values $B(E1) = 1.0 \times 10^{14}$, $B(M1) = 2.9 \times 10^{13}$, and $B(M2) = 8.4 \times 10^7$ (see Figure K.2).

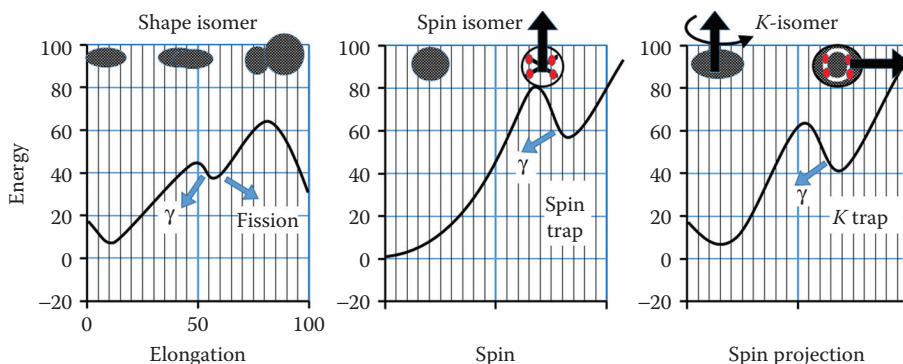


Figure K.2 Graphical representation of the K-isomerism phenomenon.

K-space

[condensed matter, computational] Abstract concept that refers to the two- or three-dimensional FOURIER TRANSFORM of the magnetic resonance image (MRI) into a data matrix consisting of the raw MRI. An MRI is a map composed of complex numbers representing the spatial distribution of the transverse magnetization: M_{xy} within the specimen (e.g., biological medium) at a specific time point as the result of an excitation by a radiofrequency perturbed MAGNETIC influence (analog to “spin echo”). The concept of *k*-space was introduced by RICHARD S. LIXES (twentieth century) in 1979 and further refined by S. LJUNGGREN (twentieth century) and independently by D. TWIEG (twentieth century) in 1983. In the convolution from temporal to spatial IMAGE space, the *k*-space in MRI defines the spatial frequency domain by two wave vectors:

$k_{FE} = \gamma_{GM} m G_{FE} \Delta t$ and $k_{PE} = \gamma_{GM} n G_{PE} \Delta t$, G_i the MAGNETIC FLUX (vector, with PHASE [PE] and frequency [FE] encoding), γ_{GM} the GYROMAGNETIC RATIO, m the sample number in the spatial domain in the FE direction, respectively n in the PE direction, where FE (representing frequency encoding) and PE (representing PHASE ENCODING) are perpendicular to each other; $\Delta t = 1/\nu$ the SAMPLING time, and ν the SAMPLING frequency. Specifically, for MRI based on the Larmor frequency $\gamma_{Larmor} = -e g_a / 2 m_e$, the gyromagnetic ratio with g_L the electron orbital g -factor e = the electron charge, m_e the mass of the precessing electron, and B the applied MAGNETIC FIELD strength. Additionally, the use of k -space in ULTRASONIC IMAGING provides a means of correlating the transmitted and received SIGNAL for deconvolution of the lateral response, assuming the “diffraction” of a monochromatic POINT SOURCE to form an approximation of the real-life conditions. The k -space occupies a spatial frequency domain (see Figure K.3).

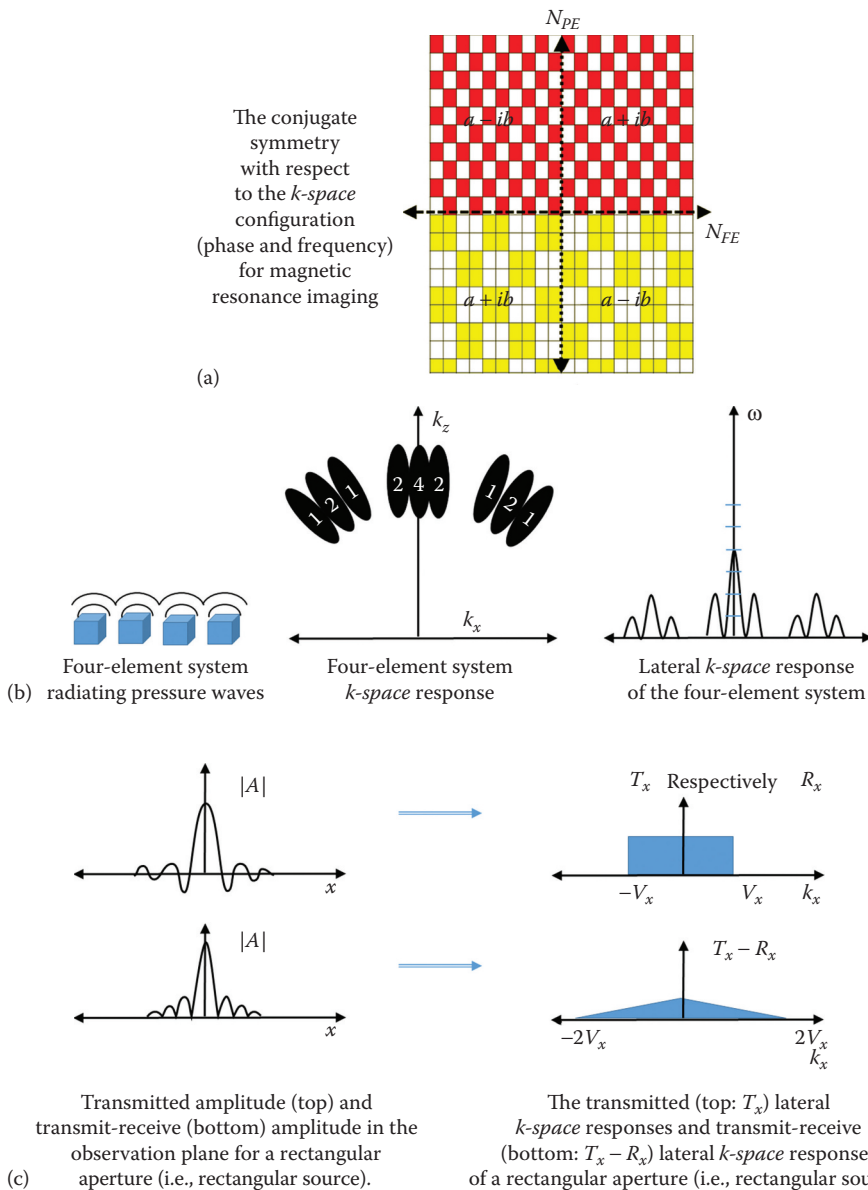


Figure K.3 (a–c) Illustration of the K -space concept in imaging, specifically for ultrasonic imaging in this case.

Kadomtsev–Petviashvili equation

[acoustics, computational, fluid dynamics, mechanics] Mathematical function for two-dimensional waves ($f(x, y, t)$) as an extension to the KORTEWEG–DE VRIES EQUATION, allowing for marginal nonlinearities and minor DISPERSION for a wide bandwidth FREQUENCY SPECTRUM as a SOLUTION to the differential equation: $d/dx \{ [df(x, y, t)/dt] + 2f(x, y, t)[df(x, y, t)/dx] + [d^3f(x, y, t)/dx^3] \} = -3\sigma^2 [d^2f(x, y, t)/dy^2]$, where σ is a constant representing the geometry of the situation. This can apply to pressure waves (i.e., ACOUSTICS), water waves, or PLASMA waves and more.

Kamerlingh Onnes, Heike (1853–1926)

[general, thermodynamics] Physicist from the Netherlands and is the discoverer of SUPERCONDUCTIVITY in 1911. A significant amount of work of Kamerlingh Onnes was in CRYOGENICS, resulting in liquefying helium in 1908, reaching the lowest temperature on record at the time of 0.9 Kelvin (0.9 K) (see [Figure K.4](#)).



Figure K.4 Heike Kamerlingh Onnes (1853–1926).

Kant, Immanuel (1724–1804)

[biomedical, general] Philosopher from Germany with influences on the modern thinking in esthetics, epistemology, ethics, and metaphysics, as well as political philosophy. The works of Kant influence the modern evolution of critical thinking, based on his statement that all observations are subjective and require analysis and independent verification. His philosophy formed the basis of modern ethics in clinical trials and human as well as animal participation in any form of research (avoiding coercion and fraud) (see [Figure K.5](#)).



Figure K.5 Immanuel Kant (1724–1804).

Kaon

[general] See *K* MESON.

Kapitza, Pyotr Leonidovich (1894–1984)

[solid-state, thermodynamics] Scientist from Russia, later USSR. Kapitza discovered the superfluidic properties of helium during his low temperature work, for which he received the Nobel Prize in Physics in 1987 (see [Figure K.6](#)).

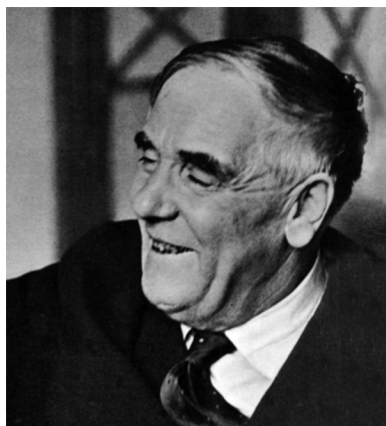


Figure K.6 Pyotr Leonidovich Kapitza (1894–1984). (Courtesy of Piotr Barącz.)

Kaplan, Irving (1913–1997)

[nuclear] Chemist and scientist from the United States, collaborator on the MANHATTAN PROJECT, the development team of the NUCLEAR BOMB. Additionally, Irving Kaplan introduced the Department of Nuclear Engineering at the Massachusetts Institute of Technology (see [Figure K.7](#)).



Figure K.7 From left to right in the picture: Dr. Irving Kaplan, Dr. Francis Bonner, Dr. E.O. Lawrence, and Dr. Harrison Scott Brown. (<http://www.gilderlehrman.org/history-by-era/postwar-politics-and-origins-cold-war/interactives/manhattan-project>; http://www.gilderlehrman.org/sites/default/files/imagecache/inline-3col-full/content-images/slide3_2.jpg.)

Kármán, Theodore von (1881–1963)

[fluid dynamics] Physicist from Hungary, with primary interests in fluid-dynamic topics related to aeronautics and astronautics (see [Figure K.8](#)).

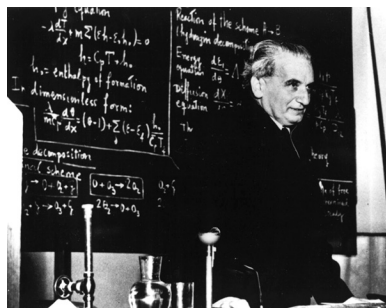
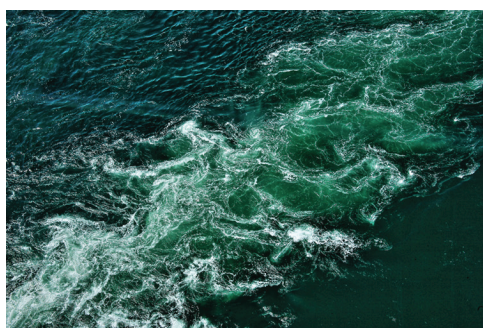


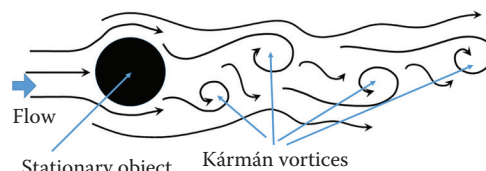
Figure K.8 Theodore von Kármán (1881–1963). (Courtesy of NASA, Washington, DC.)

Kármán eddy current vortex street

[fluid dynamics] Also referred to as Kármán vortex or Kármán street (*also see WAKE*). A VORTEX pattern in the wake of an obstruction in a FLUID flow, resulting from flow detachment from a bluff body with virtually symmetric curved pattern surface, introduced by THEODORE VON KÁRMÁN (1881–1963). The detachment or shedding will take place at different angular locations on either side of the obstruction with respect to the direction of the FLOW. For instance, in oceanic flow the obstructions can be islands, in addition to the airflow around the AIR column mounted on an island (higher temperature than the surrounding water, resulting in a microclimate) creating a vortex street of clouds based on the CORIOLIS EFFECT between the stagnant air column and the airflow. The vortex effect requires assumption of interaction with essentially cylindrical objects under conditions of a REYNOLDS NUMBER of $50 < Re < 300$. When the Reynolds number exceeds 300, the shedding progressively starts generating more TURBULENCE while developing full fluid-dynamic chaos or full turbulent flow characteristics. The shedding will occur at a rate known as the VORTEX-SHEDDING FREQUENCY (v_v), which is a function of the flow conditions and SURFACE ROUGHNESS of the bluff object. At smaller Reynolds number the flow will be laminar with little noticeable flow pattern generation. Under certain conditions, the vortex shedding frequency may match the NATURAL FREQUENCY of the obstruction/object which may result in RESONANCE, eventually leading to wide-scale impact (e.g., destructive forces, Reference: aeolian sounds, as illustrated by the TACOMA NARROWS BRIDGE). The formation of a KÁRMÁN VORTEX street on a line or wire held tightly in airflow may generate sounds known as AEOLIAN TONES (see [Figure K.9](#)).



(a)



(b)

Figure K.9 (a,b) Examples of Kármán vortices.

Katz, Bernard, Sir (1911–2003)

[biomedical, chemical, electromagnetism] Scientist from Germany who made ground-breaking discoveries in the biological cellular transmembrane ION transport and the generation of the MEMBRANE potential. Katz worked closely with SIR ALAN LLOYD HODGKIN (1914–1998), and DAVID E. GOLDMAN (1910–1998) next to SIR ANDREW FIELDING HUXLEY (1917–2012) on the transmembrane potential (*also see* GOLDMAN EQUATION) (see [Figure K.10](#)).



Figure K.10 Bernard Katz (1911–2003). (Courtesy of Society for Neuroscience, Washington, DC.)

Kaufmann, William Weed (1918–2008)

[atomic, nuclear] Nuclear scientist from the United States.

Kaufmann and Bucherer experiments

[atomic, nuclear] The determination of the momentum ($p = mv$, where v is the velocity) of elementary building blocks (electrons, etc., in the early twentieth century) with respect to its mass (m), performed independently by Walter Kaufmann (1871–1947), Alfred Heinrich Bucherer (1863–1927), and Günther Neumann (late nineteenth century–early twentieth century). These experiments were performed between 1901 and 1915 and provided verification of the special relativity concepts (*also* Kaufmann–Bucherer–Neumann experiments).

Kedem–Katchalsky formalism

[biomedical, thermodynamics] Theoretical model describing the permeability of biological membranes. The MEMBRANE is defined by hydraulic conductivity (ρ_p), reflection coefficient (σ_r), and solute permeability ($\mathbb{P}_s$). The REFLECTION coefficient is used for the transportation of water and solute, but can often be neglected. The change in volume of the cellular water and solute volume (V_{W+S}) is described as a function of the molar OSMOLALITY with respect to the inner cellular concentration ($[M]^{\text{in}}$) and extracellular concentrations ($[M]^{\text{ex}}$) for both the permeating ($\square_{\text{per}}$), and nonpermeating solutes ($\square_{\text{np}}$), expressed as $dV_{W+S}/dt = -\rho_p (\mathcal{A}R_y T) \{ ([M]_{\text{np}}^{\text{ex}} - [M]_{\text{np}}^{\text{in}}) + \sigma_r ([M]_{\text{per}}^{\text{ex}} - [M]_{\text{per}}^{\text{in}}) \}$, where $\mathcal{A}$ represents the surface area of the CELL, the GAS constant $R = 8.3144621(75) \text{ J/Kmol}$, and T the temperature, and the permeability of the solute can be defined as $\mathbb{P}_s = \omega_{\text{solute}} RT$ with ω_{solute} the mobility of the SOLUTE. Based on this the rate of change of solute (N_{sol} , in OSMOLE units) as a result of transmembrane transport (permeating the membrane) is given as $dN_{\text{sol}}/dt = [(1 - \sigma_r)/2] ([M]_{\text{per}}^{\text{ex}} + [M]_{\text{per}}^{\text{in}}) [dV_{W+S}/dt] + \mathbb{P}_s \mathcal{A} ([M]_{\text{per}}^{\text{ex}} - [M]_{\text{per}}^{\text{in}})$.

Keenan, Joseph Henry (1900–1977)

[thermodynamics] Physicist from the United States. Keenan established steam tables that were beneficial in the calculations for steam power generators next to his work on JET propulsion (see [Figure K.11](#)).



Figure K.11 Joseph Henry Keenan (1900–1977). (Courtesy of Massachusetts Institute of Technology, Cambridge, MA.)

K

Keesom, Willem Hendrik (Wilhelmus Hendrikus) (1876–1956)

[atomic, nuclear, solid-state, thermodynamics] Material scientist and theoretical and experimental physicist from the Netherlands. Willem Keesom discovered the cryogenic mechanism that allowed for LIQUID helium to be solidified. The theoretical work of Dr. Keesom involves the description of the attractive and repulsive forces between two DIPOLE formations: DIPOLE–DIPOLE INTERACTION. One specific example of the dipole–dipole attraction, or rather induced dipole (i.e., POLARIZATION, induced shifts in charge on one ATOM or MOLECULE or group of molecules by a dominant charge distribution on one of the constituents of the mixture) is in the hydrogen–chloride bond (HCl), which is not a standard example of hydrogen bonding. (*Note:* Atoms rarely form a permanent dipole, rather than molecules which will indeed form permanent dipoles.) Willem Keesom also defined the LAMBDA POINT in SPECIFIC HEAT transition for helium, a variation of the TRIPLE POINT in “high-temperature” PHYSICS (see [Figure K.12](#)).



Figure K.12 Wilhelmus Hendrikus Keesom (1876–1956). (Courtesy of Huygens ING, The Hague, the Netherlands.)

Keesom force

[atomic, nuclear, solid-state, thermodynamics] Also **KESOM INTERACTION**. Intermolecular force based on polarized DIPOLE–DIPOLE INTERACTION. The Keesom ENERGY associated with the inter-dipole force degrades with the inter-dipolar DISTANCE to the 6th power $E_{\text{attraction}}^{\text{Keesom}} = -\mu_1^2 \mu_2^2 / (4\pi\epsilon_0)^2 k_b T r^6$, which bares some resemblance to the Coulomb force ($F_{\text{attraction}}^{\text{Coulomb}} = -q_1 q_2 / 4\pi\epsilon_0 r^2$, with q_i the respective charges), with μ_1 and μ_2 the respective DIPOLE moments, $\epsilon_0 \cong 8.85418717620 \times 10^{-12} \text{ F/m}$ the DIELECTRIC permittivity in VACUUM, r the separation between the dipoles, $k_b = 1.3806503 \times 10^{-23} \text{ m}^2 \text{ kgs}^{-2} \text{ K}^{-1}$ the Boltzmann constant, and T the relative temperature (in Kelvin). In contrast, the atomic force between fixed dipoles decays with the separation DISTANCE to the third power. A different attraction is between an ION and an induced dipole, which fall under electric attraction/repulsion.

Keesom interaction

See KESOM FORCE.

Kelvin, 1st Baron (Lord William Thomson) (1824–1907)

[general, thermodynamics] British scientist and engineer and is the creator of the Kelvin scale. William Thomson proposed this scale in 1848, for which he was knighted as Lord Kelvin (see [Figure K.13](#)).



Figure K.13 Lord William Thomson; 1st Baron, Lord Kelvin (1824–1907).

Kelvin (K)

[thermodynamics] Kelvin scale, based on the constant volume THERMOMETER concept. In theory at 0 K the GAS reduces to a nonexistent volume in the limit approaching $T \downarrow 0$. The scale uses the same increments as the CELSIUS SCALE, also using the boiling point and MELTING POINT of water (373.15 K and 273.15 K, respectively) as references for calibration in a decimal configuration.

Kelvin effect

[geophysics, thermodynamics] The influence of SURFACE TENSION on the equilibrium diameter of a droplet or hygroscopic aqueous AEROSOL particle. The VAPOR PRESSURE of a droplet in suspended circumstances in

equilibrium with an aqueous solution will depend on the concentration and constituents of the SOLUTE as well as the diameter of the droplet. This condition plays a role in the determination of atmospheric conditions.

The droplet radius (r_G) as a function of surface tension (σ_{surface}), partial molar water volume for the SOLUTION ($V_{\text{MolH}_2\text{O}}$), and the ambient temperature (T) as $r_G = 2V_{\text{MolH}_2\text{O}} \sigma_{\text{surface}} / RT$, where R is the universal GAS constant.

Kelvin's circulation theorem

[fluid dynamics, thermodynamics] Fluid DYNAMICS model for a flow that has negligible viscous strain and the medium is incompressible. This may apply for boundary layers that are extremely small with respect to the FLOW phenomena, such as the AERODYNAMICS of wings of an airplane or propellers of a helicopter. Since there are no viscous forces there is no vorticity. In this model the use of a parameter called "CIRCULATION" indicates the. The circulation is the average flow velocity (i.e., wind velocity) on a path looping around the perturbation (i.e., WING), and can be represented as the closed loop integral of the vorticity within the enclosed path. Where the vorticity is the degree of "rotation" experienced in flow VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$) and time (t), which is the "curl" of the velocity at a given place. This yields for the circulation $\oint_C \vec{v}(\vec{r}, t) \cdot d\vec{s} = \oint_C \nabla \times \vec{v}(\vec{r}, t) \cdot d\vec{s}$. The circulation at the boundary of the phenomena will be finite, the outer (i.e., horizontal) edges of the wings create a VORTEX that is at the edge of the WAKE.

Kelvin's theorem of minimum energy

[fluid dynamics] An inviscid, irrotational fluid FLOW of an incompressible medium has ENERGY enclosed in an arbitrary enclosure surface (S) that describes the kinetic energy (KE_{rot}) of the VELOCITY POTENTIAL of the ideal FLUID in rotational motion. The MINIMUM ENERGY statement relates to the integral over a volume with irrotational motion compared to any other region of fluid motion with the same kinematic boundary conditions. This is expressed by integration of the all-around velocity potential (Φ_{velocity}), the rotational velocity $\vec{u}_{\text{flow}}$ defined as $KE_{\text{rot}} = \iint_{S_0} \Phi_{\text{velocity}} (\vec{u}_{\text{flow}} \cdot \vec{n}) d\vec{s} \geq 0$, where $\vec{u}_{\text{flow}} = \vec{u}_{\text{flow}} - \langle \vec{u}_{\text{flow}} \rangle$ is the vortical component of MOTION, with the irrotational velocity field: $\langle \vec{u}_{\text{flow}} \rangle = \nabla \Phi_{\text{velocity}}$ the velocity field, and $\vec{n}$ an outward normal vector to the surface $\vec{S}$. Kelvin's theorem is applied to calculate the VORTEX SHEDDING $d\Gamma/dt = 0 = [\partial\Gamma(t)/\partial t] + (\partial\Gamma_{\omega}/\partial t)$, where "omega" is the rotation "perpendicular" to the plane of the page (see Figure K.14).

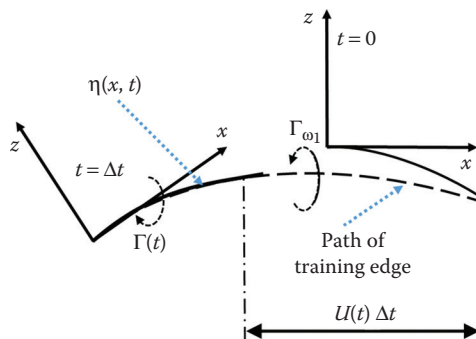


Figure K.14 Illustration of the principle of Kelvin's theorem applied to vortex shedding.

Kelvin–Helmholtz instability

[astrophysics/astronomy, computational, energy, fluid dynamics] During the FLOW of incompressible inviscid fluids with respect to each other, an external perturbation at the interface of the VORTEX sheet may create an oscillatory effect and the layers roll over, creating a MIXING layer. The shear layer between the two flow creates vorticities. The two fluids are immiscible. The layers may be AIR masses sliding over each other with respective moisture content and different temperatures and hence different densities. The shear velocity will need to be

high enough to support this effect. In solar FLUID DYNAMICS, as part of thermonuclear instabilities within a solar flame, the flare propagation becomes unstable, *see* LANDAU–DARRIEUS INSTABILITY (see Figure K.15).



(a)



(b)



(c)

Figure K.15 (a, b) Examples of Kelvin–Helmholtz instability waves. (c) Examples of Kelvin–Helmholtz instability waves. (Courtesy of Alison Bee.)

Kelvin–Helmholtz relation

[astrophysics/astronomy, computational, energy, fluid dynamics] The equilibrium between a LIQUID drop at specific TEMPERATURE (T) and the surrounding vapor with VAPOR PRESSURE (P_{vapor}) is linked to the SATURATION PRESSURE (P_{sat}) as $P_{\text{vapor}} = P_{\text{sat}}(T) \exp[2(F_s V_f' / rRT)]$, where V_f' the partial volume per unit mass of the FLUID constituent, r the bubble radius, $R = 8.3144621(75) \text{ J/Kmol}$ the GAS constant, and F_s the SURFACE TENSION.

Kelvin–Planck statement

[thermodynamics] *See also* SECOND LAW OF THERMODYNAMICS. It is not possible to convert heat into work with 100% efficacy, without experiencing losses; that is, heating of devices and ambient environment.

Kepler, Johannes (1571–1630)

[geophysics, mechanics] (syn.) {use: planetary objects orbits, planet, comet} German astronomer and mathematician. Kepler observed that PLANETARY MOTION is not necessarily circular and the velocity of the orbiting planets around the Sun is not uniform. His observations were captured by three laws (see [Figure K.16](#)).



Figure K.16 Johannes Kepler (1571–1630).

K

Kepler's first law

[geophysics, mechanics] (syn.) {use: planetary objects orbits, planet, comet} In our SOLAR SYSTEM the planets revolve around the Sun in an elliptical orbit with the Sun in one of the focal points (C_1 ; C_2). EARTH rotates around the Sun in 365.26 days, whereas HALLEY'S COMET has a period (T) of 75.32 years.

Kepler's laws

[astronomy/astrophysics, computational, general] Laws describing the MOTION of planets around the Sun known in the seventeenth century: Mercury, VENUS, EARTH, MARS, JUPITER, and SATURN. The laws describe the gravitationally defined PLANETARY MOTION based on the documented observations made by his mentor TYCHO BRAHE (1546–1601). The discovery of the planets Uranus, Neptune, and Pluto provided additional verification and validation. The laws are Kepler's first, second, and third law.

Kepler's second law (Kepler's law of planetary motion)

[geophysics, mechanics] (syn.) {use: planetary objects orbits, planet, comet} An object revolving around a PLANET or STAR marks out a path that delineates equal areas over equal time intervals, whether the orbit is a circle or an ellipse, the path trajectory is confined by the gravitational pull. In fact the orbit of the EARTH around the Sun is close to circular, but the elliptic orbit makes a significant difference. This difference is even more pronounced for HALLEY'S COMET.

Kepler's third law

[geophysics, mechanics] (syn.) {use: planetary objects orbits, planet, comet} As part of the orbital MOTION of the various planets in our SOLAR SYSTEM the trajectories of all the planets can be linked as follows: the ratio of the average DISTANCE to the Sun of each planet ($\bar{r}$) to the third power over the square of the period of rotation (T) is constant; $\bar{r}^3/T^2 = \text{Constant}$, the "Keplerian constant." The PLANET closest to the Sun, Mercury revolves in 85.5 days or 0.24 EARTH years, whereas SATURN (the outermost planet) moves with a period of 29.5 years. Satellites generally move in a circular orbit with orbital speed v_0 , confined by the CENTRIPETAL FORCE as defined by Newton's LAW OF UNIVERSAL GRAVITATION between two bodies with the SATELLITE mass m

and the planet mass M , respectively, yielding the centripetal force $F_G = G(mM/r^2)$, where the universal gravitational constant $G = 6.67259 \text{ Nm}^2/\text{kg}^2$, yielding $G(mM/r^2) = m(v_0^2/r)$, which provides one of the boundary conditions for a GEOSTATIONARY ORBIT as the velocity $v_0 = \sqrt{GM/r}$.

Kerma (K_c)

[biomedical, energy] also “collision Kerma”) Acronym for “kinetic ENERGY released in the medium,” in RADIATION THERAPY this indicates the hypothetical potential for the biological effect caused by radiation delivered at locations $\vec{r}$ in direction $\vec{s}$ with respect to the surface of an absorbing volume. The Kerma dose (K_c) is a direct function of the fluence $\vec{L}(\vec{r}, \vec{s})$ of photons with energy E that can be transferred to kinetic energy of charged particles in the medium ($E_{\text{transferred}}$) that can have ionizing effects (e.g., electrons and protons), with respect to the energy delivered per unit mass (m): $D_c = \Delta E_{\text{transferred}}/m$. The Kerma is different from the absorbed in the fact that the Kerma describes the energy transferred between the RADIATION applied and the medium the radiation is migrating through, no absorption of radiation is assumed. Kerma is expressed in gray: $[Gy] = 1 \text{ J/kg} = 100 \text{ rad}$. Kerma is different from “radiation exposure.”

Kerr effect

[energy, general, optics, thermodynamics] Change in the optical axis of a medium under the influence of an externally applied electric field and applied MAGNETIC FIELD, respectively. Also considered to be part of the BIREFRINGENCE phenomenon. The local INDEX OF REFRACTION (n) can be described in a Taylor series to depend on the local MAGNITUDE of the ELECTRIC FIELD (E) as a function of time expressed as $n(E, \vec{r}, t) = n(\vec{r}, t) + [dn(\vec{r}, t)/dE]E(\vec{r}, t) + (1/2)[d^2n(\vec{r}, t)/dE^2]E(\vec{r}, t) + \dots$. Assuming that the higher order effects are negligible this becomes the POCKELS EFFECT. In case the medium is symmetric (i.e., $(E, \vec{r}, t) = n(-E, \vec{r}, t)$), the first term is zero and the birefringence is described as dominated by the second term $n(E, \vec{r}, t) = n(\vec{r}, t) + [d^2n(\vec{r}, t)/dE^2]E(\vec{r}, t)$. Under closer examination, the index of refraction will need to consider a complex number with a real and imaginary part that respond individually to the external electric field. The Kerr effect can reach time frames in the picosecond range (see Figure K.17).

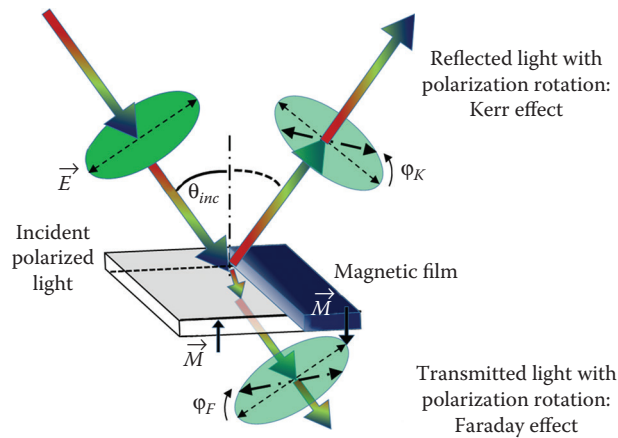


Figure K.17 Graphical representation of the Kerr effect. The Kerr effect is expressed in the reflected mode, whereas the transmitted light is subject to the Faraday effect with respect to the rotation of the electric field under the influence of an external magnetic field.

Kerst, Donald William (1911–1993)

[atomic, nuclear] Physicist and engineer from the United States. Kerst constructed a PARTICLE ACCELERATOR used for the investigation of the atomic and nuclear structure, namely, the BETATRON. The betatron uses BETA PARTICLES (i.e., electrons) to investigate the nuclear composition and the involvement of SUBATOMIC PARTICLES (see [Figure K.18](#)).

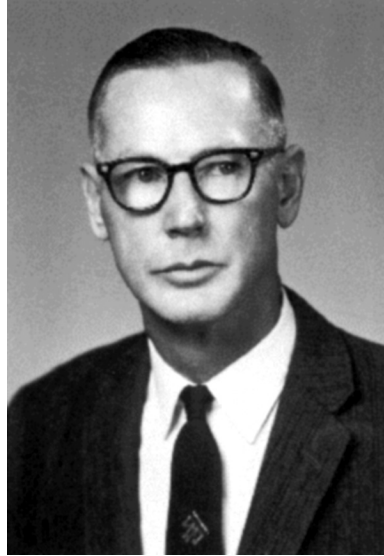


Figure K.18 Donald William Kerst (1911–1993). (Courtesy of the personal collection from the late Donald W. Kerst.)

Ketoacidosis

[biomedical, chemical] Accumulation of ketones and organic acids in the BLOOD and urine as a result of insufficient METABOLIC ACTIVITY due to lack of the hormone insulin in the blood, which affects the chemical conversion of carbohydrates. The blood GLUCOSE level in this case is often more than twice the upper limit for a healthy person over an extended period of time, usually for weeks or months. Alternatively, excessive consumption of ALCOHOL over a long period of time may also lead to ketoacidosis. Ketoacidosis may result in a

blood serum pH associated with the condition that in severe cases may drop below 7 (compared to a tightly controlled pH = 7.35 to 7.45 for a healthy adult) (see Figure K.19).

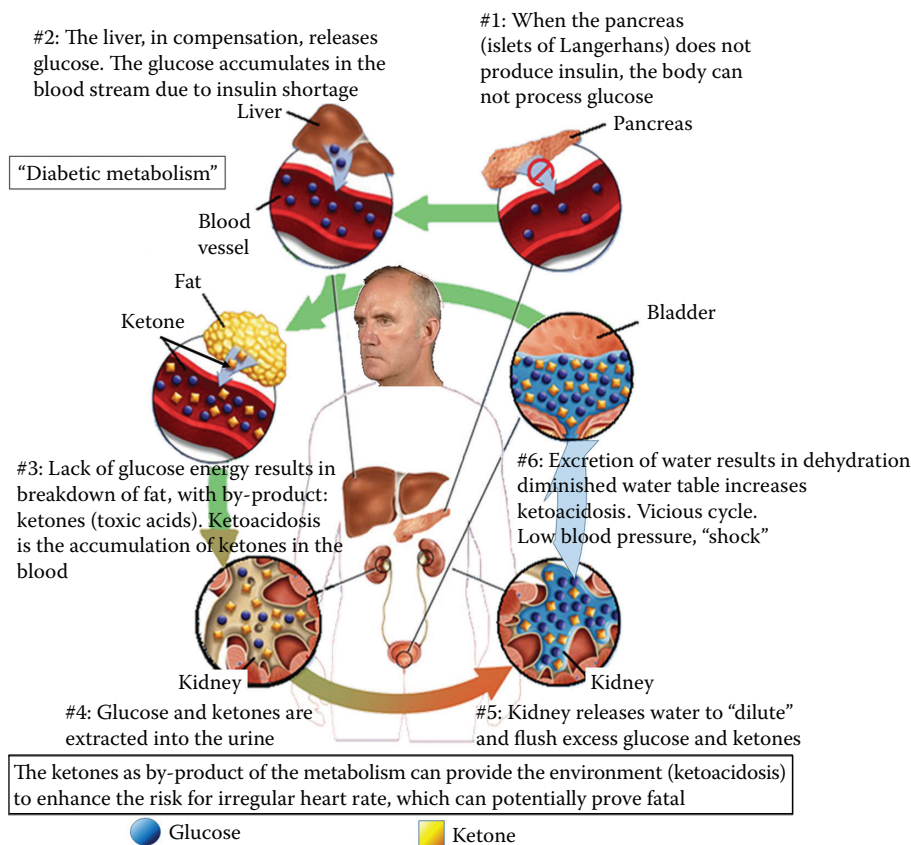


Figure K.19 Diagram explaining the process and biological implications involved in ketoacidosis.

Keulegan–Carpenter number (K_c)

[computational, fluid dynamics, mechanics, thermodynamics] Indication of fluid flow TURBULENCE. $K_c = 2\pi(a/D)$, where a is the turbulent AMPLITUDE of the FLOW behind the bluff object (i.e., cylinder) with diameter D . The value a is a flow characteristic indicating the FLUID particle motion in back-and-forth MOTION at the down flow end of the cylindrical object placed in the fluid flow. (Note: The position of the cylinder will be vertical for planar or surface WAVE interaction; e.g., tidal flow, thin cloud banks flowing over an island with an AIR column raised above.)

Kevlar®

[chemical, general, mechanics] Synthetic fiber, registered trademark of DuPont™, developed in 1965. Kevlar® is used in many medical device fabrics. It has high tensile strength per unit CROSS SECTION (greater than 3.620 MPa) and is also used in body armor as well as bicycle tires and brake linings. The woven fabric is stronger than METAL cable when submerged under water. The para-aramid holds its strength down to -196°C , and up to 260°C , with a reduction of 50% yield after exposure at or beyond this elevated temperature of 70 h or less

(higher temperatures). Kevlar® is however subject to ULTRAVIOLET degradation. An aramid is a polyamide with a minimum of 85% of the amino bonds linked to aromatic rings (see [Figure K.20](#)).

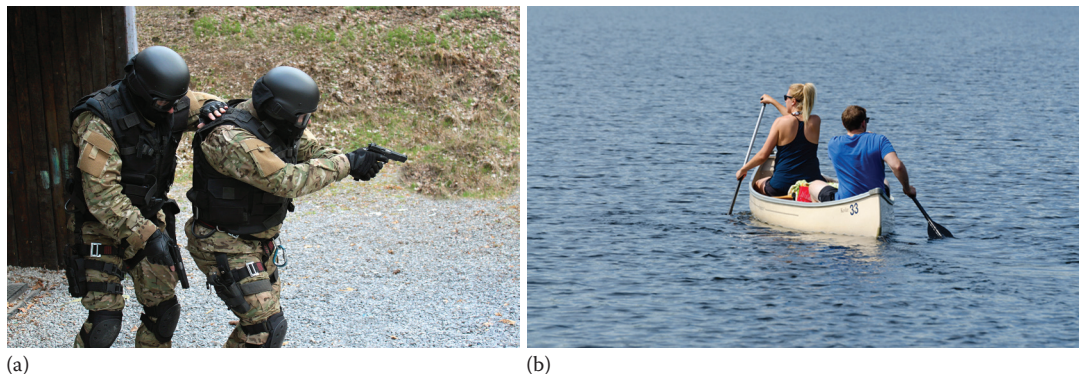


Figure K.20 (a) Special Forces persons wearing Kevlar® protective clothing. (b) Kevlar® canoe.

Kidney

[biomedical, chemical, fluid dynamics, general] Biological organ used for LIQUID purification and filtration based on OSMOTIC PRESSURE gradients. The kidney also plays a major role in maintaining the BLOOD acidity/base balance (pH level) at a very strict level, between pH = 7.35 and 7.45. The removal of unwanted chemicals from the blood is excreted from the kidney with urine (see [Figure K.21](#)).

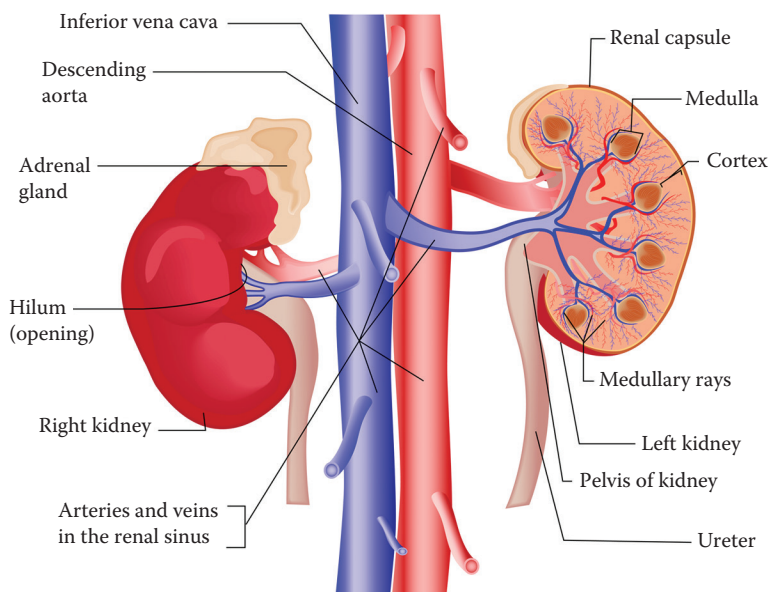


Figure K.21 Diagram of the kidney with several functions highlighted.

Kienböck, Robert (1871–1953)

[biomedical, nuclear] Physician from Austria/Germany. Inventor of a mechanism to implement dosimetry and exposure to X-RAY radiation using silver bromide paper (photographic paper). The paper becomes oxidized as a function of the exposure and after developing the paper turns a grade of gray, which can be

measured optically for QUANTIFICATION of exposure. Kienböck also identified a skeletal bone disease in which the lunate bone, specifically in the wrist, breaks down (see [Figure K.22](#)).



Figure K.22 Robert Kienböck (1871–1953). (Courtesy Collection of the Medizinischen Universität Wien—Josephinum, Bildarchiv; Vienna, Austria.)

Kill, Fredrick (1921–)

[biomedical] Scientist from Norway who invented an advanced parallel-plate KIDNEY dialysis machine in 1960, which was used through the late 1990s (see [Figure K.23](#)).



(a)



(b)

Figure K.23 (a) Fredrick Kill (1921–) and (b) kidney dialysis machine designed by Fredrick Kill.

Kilocalorie (kcal)

[general] Thermodynamic quantity used to describe the ENERGY requirement to raise 1 kg of water by 1°C. The SI equivalent is 1 kcal = 1 Cal = 4184 J.

Kilogram (kg)

[general] System International (SI) unit for mass, note that the gram is not the SI unit and is defined in 1795 as the mass of 1 l of water at 4°C. The dimensional value for 1000 g. At this moment there is a movement to use Planck's constant as the scaling factor for calibration of mass. Historically, the basis is a block of cast IRON held at the Paris Le Système International d'Unités and weighs 1.000025 l of pure H₂O.

Kinematic coefficient of viscosity (μ_K)

[fluid dynamics] The coefficient that links the FRICTION force (f_K) observed during MOTION of a mass while sliding over a surface that expresses a normal force (N) toward the object expressed as $f_K = \mu_K N$. The normal force is a function of the contact area, whereas the weight of an object is irrespective of contact to any surface. The KINETIC FRICTION is generally less than or equal to the static friction, observed when attempting to bring an object to motion. Also found as kinetic coefficient of friction or COEFFICIENT OF KINETIC FRICTION (see Figure K.24).



Figure K.24 Illustration of the kinematic viscosity of honey sliding over a spoon.

Kinematic parameters

[general, mechanics] Definitions used in either liner approximation of MOTION or in angular motion for DISTANCE, velocity, and acceleration. Linear to angular coupling is as follows: for distance, $\ell = r\theta = r \cos \theta$, with length ℓ , radius of curvature r , and ANGLE of span of segment θ ; for velocity, $v = r\omega$, with ω the ANGULAR VELOCITY; and for acceleration, $a = r\alpha$, with α the angular acceleration and the linear acceleration (a) will be in the tangential direction.

Kinematic viscosity

[biomedical, fluid dynamics, general] See VISCOSITY, KINEMATIC.

Kinematics

[general, mechanics, thermodynamics] Motion (i.e., [relative-] position and displacement) without considering the cause of relative displacement of the object or a point on an object (in contrast to DYNAMICS).

Specific topics in kinematics are velocity, acceleration, and trajectory of MOTION. Objects may be considered in relative motion with respect to each other, moving in curved motion (rotation) or in linear motion. The velocity (v) is the rate of change in location ($v = \partial x / \partial t$, note that this applies to all directions), and acceleration (a) is the rate of change in velocity ($a = \partial v / \partial t$, all with respect to direction) (see [Figure K.25](#)).



Figure K.25 Kinematics of hitting the bell on the post, “high striker.” An attraction created at the end of the nineteenth century. At that time the news was highly influenced by Hendrik Jacobus Jut (1851–1878), a waiter from The Hague, who had committed a double murder in December 1872. The game in the Netherlands hence references the hitting of the head of “Jut” (Dutch: “kop van Jut”). The patented design dates to 1908 for the United States.

Kinetic diagram

[biomedical, mechanics] Diagram of vector representation of forces, MOTION, and masses of objects in a system, as well as the definition of the physical association between the objects. In the HUMAN BODY, skeletal bones move somewhat independent of each other but are tied together by ligaments and MUSCLE mass as well as SKIN. Fixed flexing locations will have all forces balanced within the compound body. All forces can be assumed to act in the center of mass of the segment under consideration (see [Figure K.26](#)).



Figure K.26 Representation of the kinetics during a rowing motion.

Kinetic energy (KE)

[general, mechanics] ENERGY associated with movement, in contrast to potential energy which is only converted into kinetic energy when the appropriate conditions apply: $KE = (1/2)mv^2$, m the mass of the object in MOTION with velocity v (*also see ENERGY*) (see [Figure K.27](#)). For a rolling body, the kinetic energy also comes from the MOMENT OF INERTIA expressed as $KE = (1/2)Mv_{CM}^2 + (1/2)I_{MCM}\omega^2$, where the contributions of all the constituents (total mass: M) need to be accounted for in their respective influences and hence the unit of objects can be described by the center-of mass properties (subscript CM) of velocity and moment of inertia (I_M), and the object is rotating with ANGULAR VELOCITY ω (see [Figure K.28](#)).



Figure K.27 Kinetic energy on a roller coaster ride, back-and-forth conversion from kinetic to potential energy, in addition to mechanical assistance by machinery to replenish the kinetic energy based on electrical power resulting from the kinetic energy released by splitting atoms, chemical exothermic reactions, or the kinetic energy provided by wind flow.



Figure K.28 Kinetic energy of wind-powered water pumps used to drain the water from land below the water level in Kinderdijk, the Netherlands; converting wind flow energy into mechanical energy into water flow.

Kinetic energy, relativistic

[mechanics, thermodynamics] Kinetic ENERGY in relativistic terms uses the fact that velocity (v) is defined differently when particles with mass m traveling at speed close to the speed of light (c). Applying Lorentz transforms to the velocity and this rolls over into the energy as $KE_{\text{rel}} = \left\{ mc^2 / \sqrt{1 - (v^2/c^2)} \right\} - mc^2$. Note that the relativistic kinetic energy approaches infinity as the velocity of the object approaches the speed of light. The inherent requirement now also becomes that the work that needs to be performed to increase the velocity to increase to the speed of light also becomes infinitesimally large. Note that the classical kinetic energy is $KE = (1/2)mv^2$ (see Figure K.29).

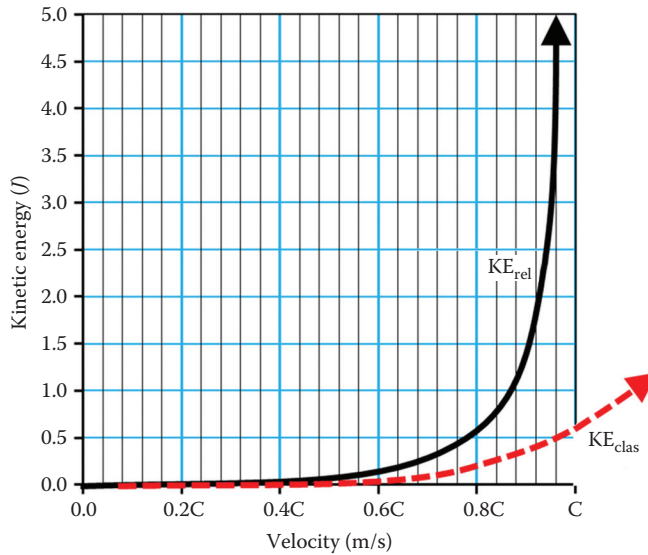


Figure K.29 Graphical representation of the relativistic approach to kinetic energy.

Kinetic energy of a bulk-flow state

[mechanics, thermodynamics] For a FLOW of mixed medium with total mass m_{TOT} , in equilibrium with or without rotation the average kinetic ENERGY can be described using the velocity of the center of mass of the total liquid (ϕ_{cm}), expressed as $KE = m_{\text{TOT}}\phi_{\text{cm}}^2/2$.

Kinetic energy of a solid moving through a liquid

[fluid dynamics] A single solid body with mass m and MOMENT OF INERTIA I , in MOTION in a LIQUID will contain both translational and rotational ENERGY and the equation becomes $KE_{\text{rot+trans}} = (1/2)[\Phi] \cdot (\vec{v} + \vec{\omega})^2$, where $\vec{v} = (v_1, v_2, v_3)$ is the translational velocity vector and $\vec{\omega} = (\omega_I, \omega_{II}, \omega_{III})$ the rotational angular velocity vector, $\vec{r}$ the location of the portion in motion, and $[\Phi]$ the VELOCITY POTENTIAL matrix coefficients, which accounts for the components of translational energy: $KE_{\text{trans}} = (1/2)mv^2$, and rotational energy: $KE_{\text{rot}} = (1/2)I\omega^2$, with the moment of inertia of the object I . The velocity potential matrix coefficients follow from the Kirchhoff theorem. The velocity potential (ϕ) is defined for the translation motion, with $(dv_1/dx_1) = [(\partial\phi/\partial x_2) + (\partial\phi/\partial x_3)] + i[(\partial\psi/\partial x_2) + (\partial\psi/\partial x_3)]$, and so on. For instance, the coefficient $\phi'_{11} = -\rho \iint \phi_1 (\partial\phi_1/\partial n) dS$, where ρ the density of the liquid, ϕ_1 is the first ELEMENT in the velocity potential, n the normal to a small but finite portion of the surface (S) of the solid. Whereas the coefficients for the angular velocity components (rotational aspects) follow from $\phi'_{jj} = -\rho \iint \Omega_j (\partial\psi_j/\partial n) dS$, where ψ is the angular velocity potential for rotational or angular motion, with ω_1 correlated to $\partial\psi/\partial\alpha$, split out in a multidimensional complex number derivative composite formulation resembling the translational velocity potential. The factor $\rho\phi$ describes the impulse pressure on the surface of the solid, while $\rho\psi$ can be

regarded as an indication of the shear stress on the surface. The choice of an appropriate reference frame is essential in limiting the complexity for solving this equation.

Kinetic energy of recoil

[nuclear] In atomic scattering the introduction of high-energy photons can result in (partial-) absorption resulting in ENERGY conversion of electron “collision,” the COMPTON EFFECT. The Compton effect transfers some of its momentum (p) to the BALLISTIC MOTION of the electron: $p = h\nu/c$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is Planck’s constant, ν the electromagnetic frequency, and c the speed of light. The kinetic energy of the electron with REST MASS m_0 resulting from PHOTON recoil is $\text{KE}_e = mc^2 - m_0c^2 = m_0c^2 \{ [1/\sqrt{1-(v^2/c^2)}] - 1 \}$, where v is the recoil velocity of the electron (see [Figure K.30](#)).



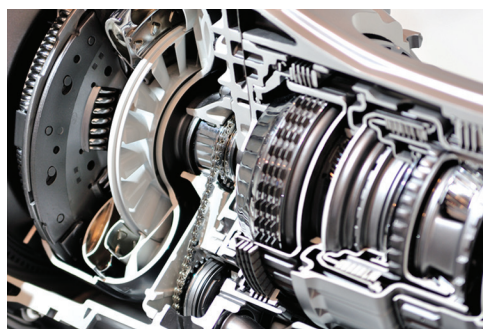
Figure K.30 The recoil of a ball thrown at the target of a dunk tank will trip a level that makes the person seated fall into the water basin.

Kinetic friction

[general] Force experienced by an object in MOTION while in contact with another system. The FRICTION force is opposite to the direction of motion, or opposite the applied external force that initiates the motion. Kinetic friction is frequently greater than static friction, meaning that it is harder to bring an object into motion than maintaining motion (see [Figure K.31](#)).



(a)



(b)

Figure K.31 (a) Kinetic friction exerted by disk brakes to achieve a reduction in velocity of a moving vehicle. (b) A similar principle applies to the clutch of a gear transmission to the drive axle, only to match the angular velocity of two axles.

Kinetic stability

[fluid dynamics] In a tidal WAVE, or wave-like MOTION of AIR mass (e.g., KELVIN–HELMHOLTZ INSTABILITY), the conditions for stability are defined by the relationship between the kinetic ENERGY in the relative motion of the rolling wave ($KE_{\text{rol_rel}} = (1/2)\sum m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2)$, where $\dot{x} = \partial x / \partial t$), the potential energy of the crest and trough of the wave phenomenon (U_{wave}) and the rotational kinetic energy ($KE_{\text{rot}} = (1/2)\omega^2 \sum m(x^2 + y^2)$ without relative motion within the system, assuming forward motion in the z -direction and the wave performs a circular motion with ANGULAR VELOCITY ω , with volume of average mass m). The stability is defined by $KE_{\text{rol_rel}} + (U_{\text{wave}} - KE_{\text{rot}}) = \text{Constant}$. In case of the absence of external forces the following conditions also applies: $\Delta \int_0^t (KE_{\text{Trot}} - U) dt = 0$, where $KE_{\text{Trot}} = KE_{\text{rol_rel}} + KE_{\text{rot}} + \omega I'$, with $I' = \sum m(xy - y\dot{x})$. In this scenario, the relative coordinates (x, y, z) can be replaced for small disturbances by the displacements (d_i) in linear transformation for a three-dimensional format, resulting in a vector formulation: $KE_{\text{rol_rel}} = (1/2)(c_1 \dot{d}_1^2 + c_2 \dot{d}_2^2 + \dots + c_n \dot{d}_n^2)$ and $(U_{\text{wave}} - KE_{\text{rot}}) = (1/2)(e_1 d_1^2 + e_2 d_2^2 + \dots + e_n d_n^2)$, where the coefficients c_i are the principal coefficients of INERTIA and e_i are the principal coefficients of stability.

Kinetic theory

[general] Concept of MOLECULAR MOTION transferring ENERGY as first introduced by PLATO (427–347 BC) and reaffirmed by GALILEO GALILEI (1564–1642) and described theoretically by SIR FRANCIS BACON (1561–1626). The principles of kinetic theory were further refined by JAMES CLERK MAXWELL (1831–1879) around 1860 and later by LUDWIG EDUARD BOLTZMANN (1844–1906). Also found as “kinetic theory of gases.” The kinetic theory provides the basis for the definition of temperature (T) as the average kinetic energy: $T = (2/3k_b) \sum m_i v_i^2$, where m_i is the respective mass of the constituents, v_i the velocity of the individual mass units, and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ Boltzmann coefficient. Using kinetic theory the PRESSURE (P) of a GAS can be expressed in terms on KINETIC ENERGY (KE) as $P = (2/3)(NKE/V)$, where N is the number of gas particles and V the gas volume.

Kinetic theory versus caloric theory

[general] CALORIC THEORY, introduced in the 1760s defined THERMAL ENERGY as a fluid; CALORIC. Caloric was supposedly indestructible and could not be created. This medium of energy was a radical change from concepts of internal MOTION hypothesized as far back as PLATO (427–347 BC). The work of BENJAMIN THOMPSON (COUNT RUMFORD) (1753–1814) repealed the caloric concept in 1798 to the base concepts of Plato and further theoretical evolution of the KINETIC THEORY, reiterating that work performed can generate heat.

Kinetics, chemical

[chemical, nuclear] The chemical kinetics consider the rate processes of chemical reactions and the ENERGY exchange between the initial and final components. For a chemical reaction with components with respective concentrations $[A]$, $[B]$, and end products $[C]$, $[D]$, and respective fractional quantities in the reactions a, b, c, d , the reaction can be described as $a[A] + b[B] \rightleftharpoons c[C] + d[D]$. This yields a chemical reaction rate $v_{\text{chem}} = -(1/a)(d[A]/dt) = -(1/b)(d[B]/dt) = -(1/c)(d[C]/dt) = \dots$. This chemical reaction rate can also be written with respect to the reaction rate constant (k_{chem}), which also relies on

the presence of chemical species ($[K]$) that are not directly involved in the chemical reaction, but that do influence the energy state (can be a catalyst), or more generally provides a charge exchange mechanism: $v_{\text{chem}} = k_{\text{chem}} [A]^{\alpha} [B]^{\beta} [C]^{\gamma} [D]^{\delta} [K]^{\kappa}$, the reaction factors $\alpha, \beta, \gamma, \delta$, and κ are real numbers. The reaction is generally a function of temperature (T) and well as the respective concentrations and their ratio. The chemical rate constant is linked to the reaction activation energy (E_{chem}) as $k_{\text{chem}} = A \exp(-E_{\text{chem}}/RT)$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant, and $A = (N/V) (m/2\pi k_b T)^{3/2}$ an Arrhenius constant derived from the total number of particles: $N = \iint f d^3x d^3v$, the Maxwell distribution of particles (also referred to as the MAXWELL–BOLTZMANN DISTRIBUTION), integrated over space: $d^3x = dx dy dz$ as a function of location and as a function of velocity $d^3v = dv_x dv_y dv_z$, and the BOLTZMANN COEFFICIENT $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$.

Kinetics, nuclear

[nuclear] Generally, the ENERGY content of nucleotides and electrons needs to be handled in relativistic terms or approaches this. The equivalence of mass and energy forms the foundation of all nuclear energy projects. The mass–energy concept can be converted into heat and can be used to generate steam to drive a TURBINE that generates ELECTRICITY. The kinetic energy of nucleotides and potentially electron as well, each with respective REST MASS m_0 is $\text{KE}_{\text{nuclear}} = mc^2 - m_0c^2 = mc^2 \left\{ \left[1/\sqrt{1-(v^2/c^2)} \right] - 1 \right\}$, where v is the velocity of the PARTICLE, c the speed of light, and $E = mc^2$ is the rest mass energy.

Kinetostatics

[fluid dynamics] Fluid-dynamic system in cyclic motion. Since the time average translates to a quasistatic event this term was introduced to solve the equilibrium conditions of flow. The ENERGY is in this case represented by a static component (KE_{stat}) and a dynamic component (KE_{dyn}), which can be differentiated with respect to locations in system (χ_i) to obey $(\partial \text{KE}_{\text{stat}} / \partial \chi_i) + (\partial \text{KE}_{\text{dyn},0} / \partial \chi_i) = 0$. Under these conditions, the forces ($F_{Q,i}$) influencing the FLOW aspects that neutralize the pressure of the solids on the liquids to neutralize the cyclic influences expressed as the components of the extraneous forces: $F_{Q,i} = \partial \text{KE}_{\text{stat}} / \partial \chi_i$; note that the flowing LIQUID expresses forces in the form $F_{Q,i}' = \partial \text{KE}_{\text{dyn}} / \partial \chi_i$, due to the equilibrium condition. The solids can be walls and blades or particles (see Figure K.32).

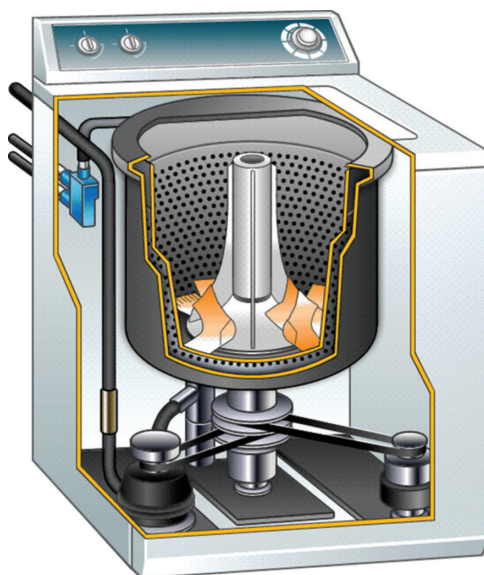


Figure K.32 Kinetostatics in a rotating central agitating top loader washing machine.

Kink

[computational, quantum, thermodynamics] Mathematical artifice, specifically used in field theory. The “kink” can define the POTENTIAL WELL pertaining to a free electron in a doped CONDUCTOR, specifically with respect to the theoretical formulation of the KONDO EFFECT and the electrical conductivity “around” an atomic LATTICE impurity.

Kirchhoff, Gustav Robert (1824–1887)

[electromagnetism, general, optics] Physicist from Germany. Kirchhoff postulated and verified several rules for electrical circuits; the Kirchhoff rules: “loop” and “node” rules. Additional work of Kirchhoff provided the radiation law. During a collaborative effort with ROBERT WILHELM EBERHARD BUNSEN (1811–1899) they performed optical experiments, identifying spectral profiles of molecules in the ATMOSPHERE. This work was instrumental in explaining the theoretical and experimental work by JOSEPH VON FRAUNHOFER (1787–1826) on the “FRAUNHOFER LINES” (see [Figure K.33](#)).

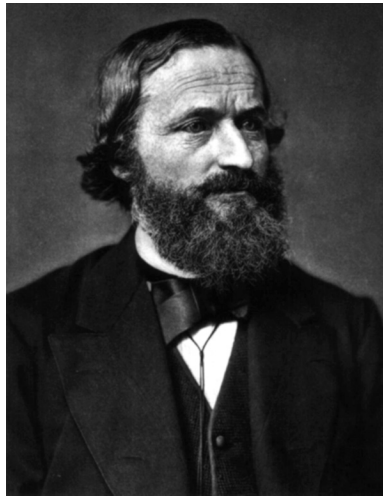


Figure K.33 Gustav Robert Kirchhoff (1824–1887).

Kirchhoff radiation integral

[acoustics, fluid dynamics] In the detection scheme for acoustic and in general pressure WAVE signals, the velocity potential function (ϕ) as a function of location can be found by integration of the direct beam using the Fourier double integral theorem. The FLUX of ACOUSTIC WAVES is found for irrotational MOTION as $\Phi = -\iint (\partial\phi/\partial n) dS = -\iint f(t) dS$, where n is the normal vector to the surface (S) of integration. The simple HARMONIC OSCILLATION is solved using GREEN'S THEOREM, providing the VELOCITY POTENTIAL at any point (P). The Kirchhoff integral providing the “FLOW” in any point as a function of time (t), at location $\vec{r} = (x, y, z)$ with respect to the reference frame with P as the origin, is given as $\phi_P(t) = -(1/4\pi) \iint f(t - (r/v_{\text{sound}}))/r dS + (1/4\pi) \iint (\partial/\partial n) [\phi(t - (r/v_{\text{sound}}))]/r dS$, where v_{sound} is the local speed of SOUND. Also referred to as Kirchhoff's integral of the general equation of sound.

Kirchhoff's laws

[biomedical, electromagnetism, solid-state] There are three laws or rules postulated by Kirchhoff: LOOP RULE; node rule, and the radiation law. KIRCHHOFF'S LOOP RULE defines the CONSERVATION OF ENERGY by calculating the sum of all the electrical potentials in an electrical circuit for any loop and this should add up to zero. KIRCHHOFF'S NODE RULE defines the CONSERVATION OF CHARGE for any node in an electrical circuit requiring the sum of the currents to equal zero, hence no charge accumulation. A node, or junction, is a connection of two or more wires. The KIRCHHOFF'S RADIATION LAW describes the equilibrium between absorbed RADIATION and black-body radiation from the walls of a system. The Kirchhoff laws can be used to reduce the complexity of a system by step-wise replacing inner loops by single component circuit loops, hence gradually reducing the total number of loops in a circuit (e.g., replacing parallel paths with a single equivalent path). Frequently the use of the Kirchhoff rules is combined with OHM'S LAW. The Kirchhoff laws can be applied to fluid-dynamic principles using the equivalence of pressure with voltage and FLOW with current.

Kirchhoff's loop rule

[electromagnetism, general] In an electrical circuit the sum of all the electrical potentials in any loop adds up to zero. A loop constitutes a continuous electrical path, including electronic components such as capacitors, resistors, and inductors (*also* KIRCHHOFF'S VOLTAGE LAW) (see [Figure K.34](#)).

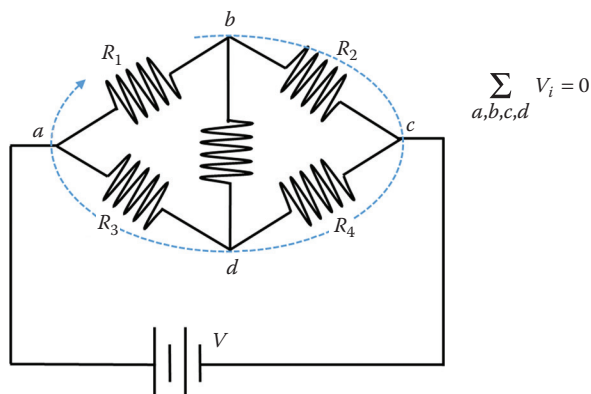


Figure K.34 Diagram of Kirchhoff loop rule.

Kirchhoff's node rule

[electromagnetism, general] In an electrical circuit at any node the sum of the currents equals zero, that is, no charge accumulation. A node, or junction, is a connection of two or more wires (*also* **KIRCHHOFF'S CURRENT LAW**) (see [Figure K.35](#)).

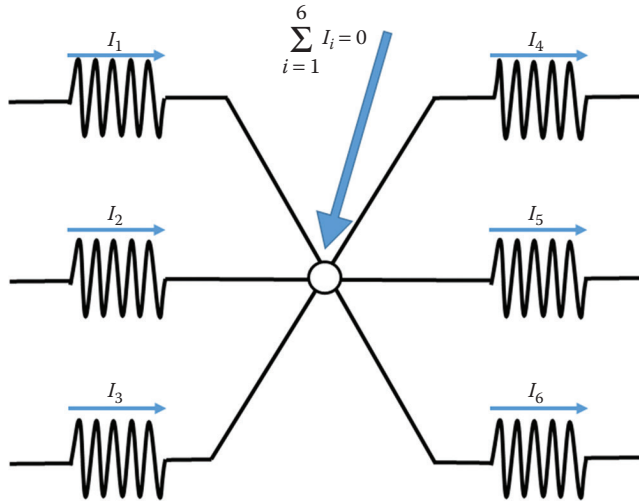


Figure K.35 Diagram of Kirchhoff node rule.

Kirchhoff's radiation law

[general, optics] The total amount of **ENERGY** absorbed by the walls of a system in **THERMAL EQUILIBRIUM** will emit an equal amount of **RADIATION** on thermal emission. The absorbed photon energy will be a fraction of the total thermal (i.e., infrared and visible) radiation energy **MAGNITUDE** with a wavelength-dependent distribution function: I_λ . The **PHOTON** energy absorbed within a certain bandwidth ($\Delta\lambda$, the radiation band) will experience a particular absorption coefficient: α_λ . The energy emission (ϵ_λ) may be in a respectively different wavelength region (i.e., lower or equal energy band), expressed as $\epsilon_\lambda/\alpha_\lambda = I_\lambda$ (*also see* **BLACK-BODY RADIATION**) (see [Figure K.36](#)).

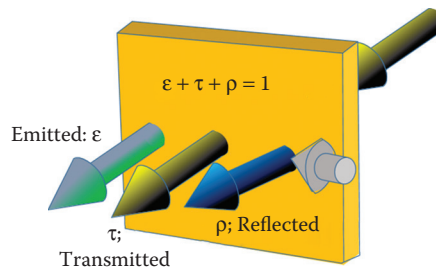


Figure K.36 Kirchhoff's radiation law.

Kirkwood gap

[astrophysics/astronomy, computational] Gaps or dips in the semimajor axis distribution of main-belt **ASTEROIDS** within the asteroid belt (i.e., the rings of **JUPITER**, a set of three concentric dense **PARTICLE** and dust torus belts) as a result of gravitational interactions with the **PLANET** Jupiter, equivalently the gaps can be

localized by orbital period. The gaps were recorded and explained by DANIEL KIRKWOOD (1814–1895) in 1886 (see [Figure K.37](#)).

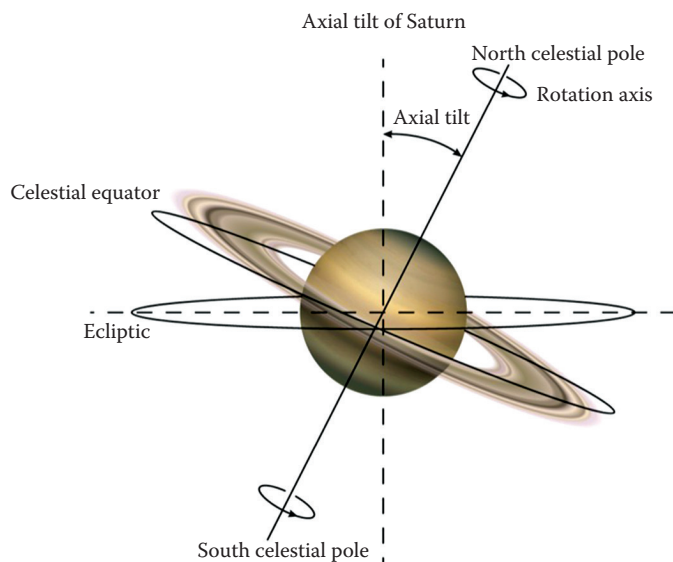


Figure K.37 Kirkwood gap for Saturn's rings.

Kissing number ($K(d)$)

[computational, geometry] In space defined by d -dimensions, the maximum number of individual unit spheres of equal size that can touch a given sphere (centered) with same dimensions. In two dimensions ($d = 2$); $K(2) = 6$ and in three dimensions $K(3) = 12$ (see [Figure K.38](#)).

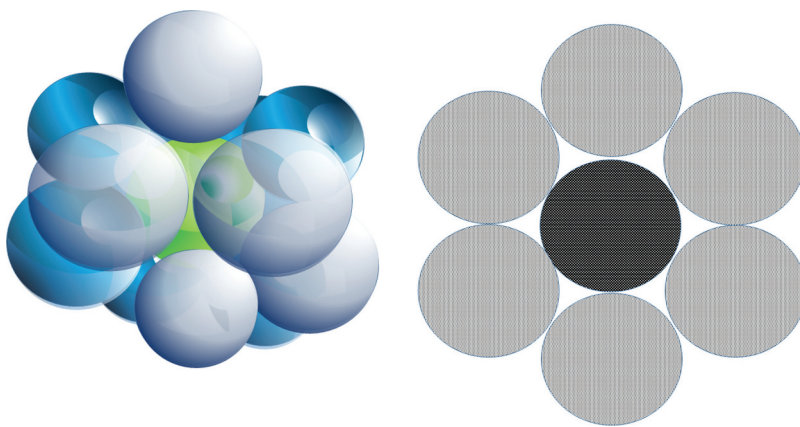


Figure K.38 Graphical representation of the Kissing number phenomenon.

Kittel, Charles (1916–)

[computational, nuclear, quantum, solid-state] Physicist from the United States. Kittel is well known for his contributions to SOLID-STATE and theoretical PHYSICS. Author of several established and recognized reference books (see [Figure K.39](#)).



Figure K.39 Charles Kittel (1916–).

Kleist, Ewald Jurgens von (1700–1748)

See VON KLEIST, EWALD JURGENS (1700–1748).

Kline bursting phenomenon

[fluid dynamics] Periodicity in turbulent events: “bursts” as discovered by Stephen Jay Kline (1922–) in 1967, using hydrogen BUBBLES (i.e., “trace technique”) in turbulent BOUNDARY LAYER in AIR. The REYNOLDS

NUMBER where this phenomenon has been observed range from $Re = 1505$ to $Re = 2492$. This phenomenon also defines the under-water periodicity of ridges found near the shore of a sandy beach (see [Figure K.40](#)).



(a)



(b)

Figure K.40 (a) Kline bursting phenomenon as experienced at the beach under the tidal water flow, running parallel to the shoreline and (b) in the desert due to wind blowing over the surface, respectively.

Klystron

[electronics, mechanics, radiation, solid-state] Vacuum tube that has a CATHODE ray (i.e., electron beam) which is modulated in applied voltage, hence modulating the electron beam velocity profile. The electron beam thus creates density fluctuations and gradients. The klystron can act as a MICROWAVE amplifier or as an OSCILLATOR. During modulation the electron FLOW forms a WAVE pattern where fast electrons gain on slow electrons and overtake (DISPERSION), causing the electron density to fluctuate (see [Figure K.41](#)).

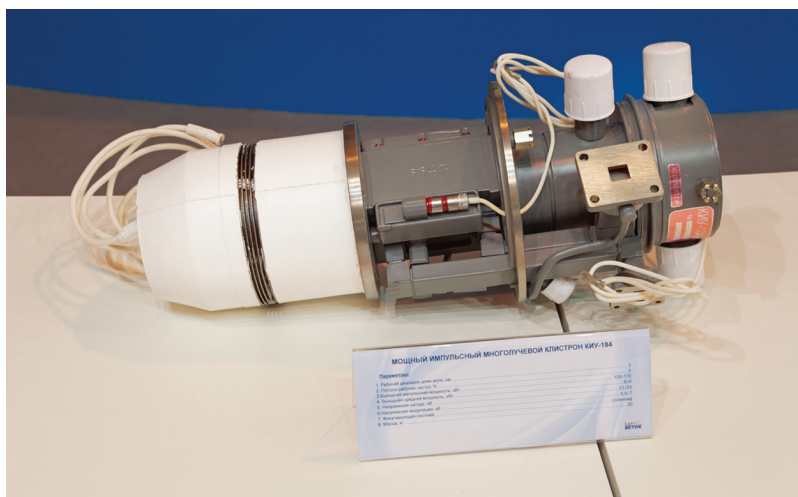


Figure K.41 Klystron.

Knee extensor

[biomedical] Muscle connected to the tibia to extend the lower part of the LEG, for instance, to kick a ball or ride a bicycle. The knee-extensor mechanism is formed by a complex integration of muscles, ligaments, and tendons. The knee extensor interaction is designed to stabilize the patellofemoral joint. The patellofemoral joint consists of the knee cap (patella) and the end of the thigh bone (femur) (see [Figure K.42](#)).

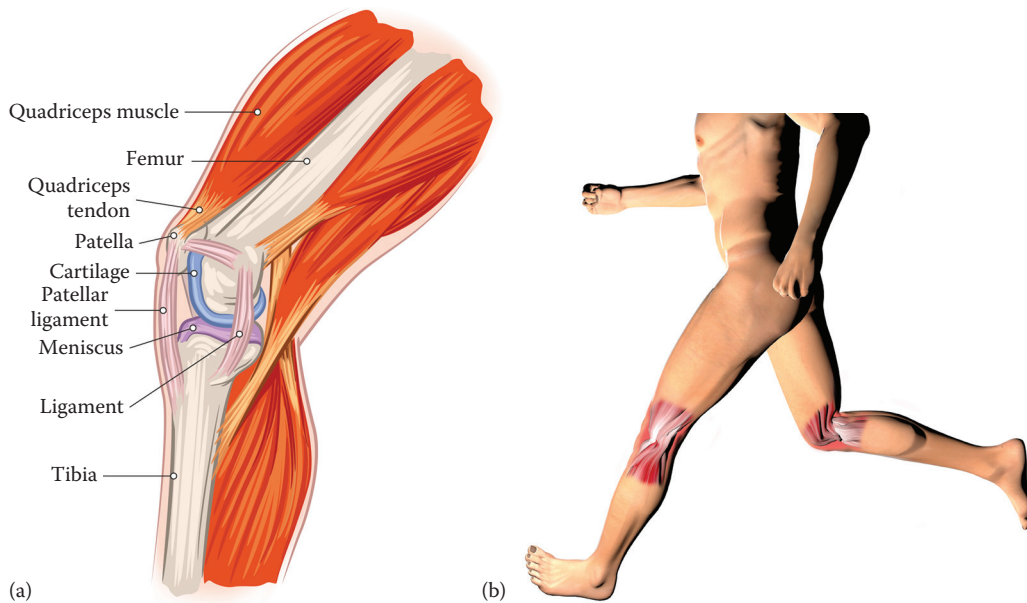


Figure K.42 (a) Knee extensor detail and (b) functional diagram of knee extensor during running.

Knife-edge detector

[acoustics, optics] A detector that is demarcated by an edge that is thin with respect to the phenomenological wavelength, in order to minimize edge effects resulting from diffraction.

Knight, Walter David (1919–2000)

[nuclear, solid-state] Physicist from the United States. Knight is best known for his discovery of frequency shifts of the nuclear magnetic resonance frequency spectrum (NMR) observed in (paramagnetic-) METAL

exposure, named after him: Knight shift. The shifts appear to be linked to electric quadrupole resonance and MAGNETIC RESONANCE in metal LATTICE and crystalline structures (see [Figure K.43](#)).



Figure K.43 Walter David Knight (1919–2000). (Courtesy of the Physics Department, UC Berkeley, Berkeley, CA.)

Knipping, Paul (1883–1935)

[atomic, nuclear] Physicist from Germany. Experimental physicist whose work on excitation/IONIZATION ENERGY for hydrogen and helium formed the basis of the helium LYMAN SERIES. Additional work by Knipping involved the X-RAY diffraction analysis of the atomic structure of crystals, deriving the LATTICE matrix and general regularities (see [Figure K.44](#)).



Figure K.44 Paul Knipping (1883–1935).

Knudsen, Martin Hans Christian (1871–1949)

[computational, fluid dynamics, mechanics, thermodynamics] Danish physicist specialized in FLUID DYNAMICS and more specifically RHEOLOGY. Knudsen introduced the kinetic molecular theory, primarily in

relation to low-pressure GAS phenomena. He was instrumental in the development of what is now known as the Knudsen CELL, one of the primary components in MOLECULAR BEAM EPITAXY systems (see [Figure K.45](#)).



Figure K.45 Martin Hans Christian Knudsen (1871–1949) in 1934, photographed by Friedrich Hund.

Knudsen number ($\text{Kn}=\lambda/L$)

[computational, fluid dynamics, mechanics, thermodynamics] Dimensionless number in GAS mechanics used to determine the computational regime for staging the mathematical approach. Ratio of the free path for MOLECULAR MOTION ($\lambda_{\text{molecule}}$) and a characteristic length of the system (L): $\text{Kn} = \lambda_{\text{molecule}}/L_{\text{char}} = kT/\sqrt{2}\pi\sigma^2PL$, where k is the BOLTZMANN CONSTANT ($1.3806504(24)\times 10^{-23}$ J/m, T the temperature of the system, σ the PARTICLE hard shell diameter, and P the pressure. Primarily originating from the computational needs in FLUID DYNAMICS for RHEOLOGY and rarified gases, specifically related to momentum transport theory. For instance, a Knudsen number of $\text{Kn} \leq 0.1$ sets the boundary conditions where the FLUID can be treated as a continuous medium, with the MACROSCOPIC parameters such as pressure, temperature, volume, velocity, and density. More confined is the regime: $0 < \text{Kn} \leq 0.1$, describing slip flow. No slip flow is characterized by $\text{Kn} = 0$. Under the condition of $\text{Kn} \geq 1$, the theoretical approach for the fluid requires a MICROSCOPIC or molecular approach. Specifically under the conditions of $\text{Kn} \geq 1$, the trajectories of individual molecules need to be mechanically analyzed as macroscopic variables. Additionally, for $\text{Kn} \geq 10$ there are no statistically significant molecular interactions and the fluid is considered to be free molecular or collisionless. The segment $0.1 < \text{Kn} < 1$ is the transition slip flow regime, treating the fluid as a continuous medium allowing for discontinuities at the boundaries in characteristics such as temperature and velocity while the FLOW transitions from diffusive (CONTINUUM) to ballistic or free molecular flow. The Knudsen number expresses the ratio of the mean free path length of molecular MOTION (e.g., BROWNIAN MOTION) with respect to a characteristic length. The MEAN FREE PATH is inversely proportional to the fluid density. The characteristic length will be a direct function of the situation that needs to be computed, such as the dimensions and shape of an object submerged in a LIQUID or the diameter of a fluid flow in a PIPE. An archetypal example of a small characteristic length is the flow of an AEROSOL through small diameter APERTURES and small size tubing. The Knudsen conditions will require Monte Carlo simulations in order to solve the fluid dynamics issues under the complex boundary conditions. The Knudsen number indicates the validity of either line of sight ($\text{Kn} > 1$) or continuum ($\text{Kn} < 0.01$) for gas models.

Koch curve

[computational] Fractal line, defined by a mathematical function, derived by the Swedish mathematician HELGE VON KOCH (1870–1924) in 1904. One of the first fractal images described, also known as the Koch snowflake. The Koch curve can be constructed by an iteration process starting out from an equilateral

triangle. The edges of the triangle are subdivided into three equal length segments, and a new triangle is drawn outward from the central segment, and the base segment is removed. This process is repeated for as many times as possible, starting each time with the outward facing two edges of the equilateral triangle. Over time, the shapes have been modified with artistic flare.

Köhler curve

[fluid dynamics, geophysics, thermodynamics] Plot of the KÖHLER EQUATION illustrating the point of supersaturation where the cloud droplet is in equilibrium with the environmental conditions over a range of droplet radii. The shape and value of the Köhler curve will depend on the constituents of the droplet as well as relative and absolute concentrations, respectively (see Figure K.46).

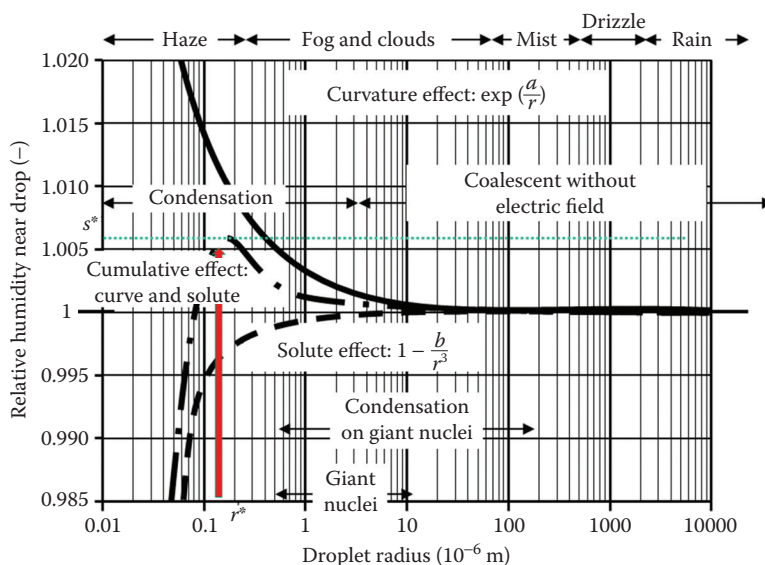


Figure K.46 Köhler curve.

Köhler equation

[fluid dynamics, geophysics, thermodynamics] Theoretical equilibrium saturation (S_{eq}) with respect to the KÖHLER THEORY, in which the formation of clouds from water vapor condensation is described as $S_{eq} = \exp\left[\left(2M_w\sigma_s/RT\rho_w r\right) - \left[n_{ion}\Phi_{osm}M_w(m_s/M_s)/((4/3)\pi\rho_{particle}r^3 - (m_s - m_{insol}))\right]\right] = RH/100\%$, with M_w the MOLECULAR WEIGHT of water, Φ_{osm} the osmotic coefficient, n_{ion} the number of ions giving the VAN'T HOFF FACTOR: $n_{ion} \times \Phi_{osm}$, σ_s the SURFACE TENSION of the LIQUID medium with SOLVENT, R the IDEAL GAS constant, T temperature, ρ_w density of the water, $\rho_{particle}$ the colloid particulate density in the haze (fog) with SATURATION s , m_s the mass of the SOLUTE, M_s the molecular weight of the solute, $m_s = (1 - \epsilon_{insol})m_{insol}$ the soluble PARTICLE mass, ϵ_{insol} the insoluble mass fraction, $m_{total} = m_s + m_{insol}$ the total mass of the AEROSOL, m_{insol} the insoluble mass of the aerosol particulate, and r the aerosol particle radius (i.e., radius of droplet in cloud). In this equation the second term represents the molar ratio of solute to water at a given relative HUMIDITY.

Köhler theory

[fluid dynamics, geophysics, thermodynamics] Theory describing the formation of clouds from water vapor condensation. The Köhler theory combines the SATURATION PRESSURE of a medium described by RAOULT'S LAW with the changes in VAPOR PRESSURE resulting from a curved surface formulated in the KELVIN EFFECT.

Kohlhörster, Werner Heinrich Gustav (1887–1946)

[atomic, nuclear] Physicist from Germany. Scientist involved with the description of terrestrial ELECTRICITY, predominantly the IONIZATION in the ATMOSPHERE, not limited to the IONOSPHERE. He also studied the circadian variations in RADIATION reaching the earth's surface under the influence of the reshaping of the electronic composition and gradients in Earth's ATMOSPHERE. Contemporary and contributor in global efforts with PIERRE VICTOR AUGER (1899–1993). Kohlhörster used balloons to collect his data, traveling to heights of 9,300 m (see [Figure K.47](#)).



Figure K.47 Werner Heinrich Gustav Kohlhörster (1887–1946).

Kohlrausch, Friedrich Wilhelm Georg (1840–1910)

[general] Scientist from Germany. Kohlrausch researched the conductive properties of conductive media, more specifically electrolytes. Together with WILHELM EDUARD WEBER (1804–1891) they derived the DIELECTRIC permittivity ($\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$) and permeability ($\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$) in 1856, which was later combined with the speed of light measured in 1849 by ARMAND HIPPOLYTE LOUIS FIZEAU (1819–1896) and by JAMES CLERK MAXWELL (1831–1879) in 1865 as: $c = (\epsilon_0 \mu_0)^{-1/2}$ (see [Figure K.48](#)).

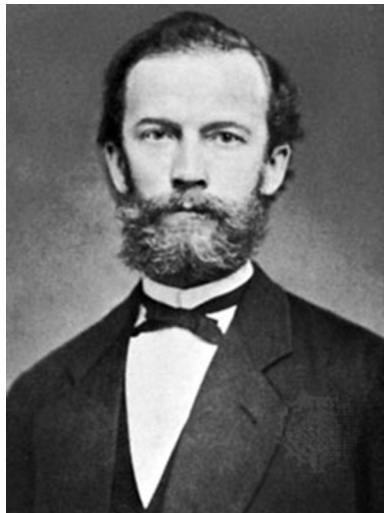


Figure K.48 Friedrich Wilhelm Georg Kohlrausch (1840–1910). (Courtesy of Otto Patzig.)

Kohn anomaly

[atomic, solid-state, thermodynamics] Phonon spectrum associated with electron–phonon interaction in CHARGE DENSITY WAVES, introduced by Walter Kohn (1923–). Under the influence of dopings in, for instance, metals or SEMICONDUCTORS, the Raman spectrum is changing due to DISPERSION. The Kohn anomaly predominantly lowers the density wave (phonon) ENERGY with respect to charge density waves in LATTICE structures. Discontinuities in the FREQUENCY SPECTRUM derivative indicates lattice distortions (see Figures K.49 and K.50).

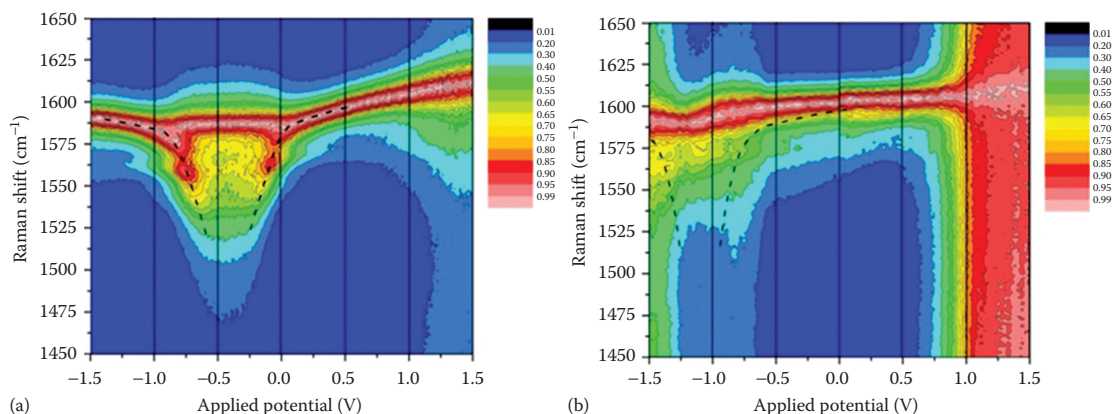


Figure K.49 Kohn anomaly shift illustrated by the Raman scattering map of the charge density waves (phonon wave) for charged virgin single-walled carbon nanotubes (a) and CuCl-doped single-walled carbon nanotubes (b). (Courtesy of 2011 Andrei Eliseev, Lada Yashina, Marianna Kharlamova, and Nikolay Kiselev. Originally published in [short citation] under CC BY-NC-SA 3.0 license. Available from: <http://dx.doi.org/10.5772/19060>.)



Figure K.50 Walter Kohn (1923–). (Courtesy of Markus Pössel.)

Kolff, Willem Johan (1911–2009)

[biomedical, chemistry, fluid dynamics] Physicist, engineer, and scientist from the Netherlands who perfected the dialysis machine used by GEORGE HAAS (1886–1971) in 1943; pioneer in hemodialysis. Another artificial

organ invented by Kolff is the artificial HEART. The design is different from the artificial KIDNEY invented by JACK RACK LEONARDS (1919–1978) and LEONARD T. SKEGGS, JR. (1918–2002) (see [Figure K.51](#)).

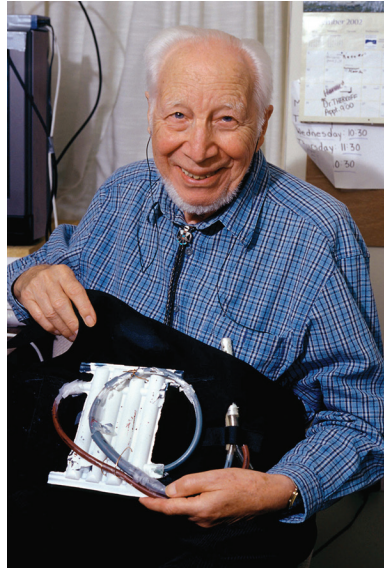


Figure K.51 Willem Johan Kolff (1911–2009).

Kolff kidney

[biomedical] Rotating wooden drum wrapped in a CELLOPHANE membrane, new material at the time of introduction in 1947. The constructed centrifuge had tubing coiled around the drum, which was submerged in a SOLUTION of electrolytes (carefully selected chemicals configuring a solution called “dialysate”) that applied OSMOTIC PRESSURE to circulating arterial BLOOD for DIFFUSION of uremic toxins. The arterial blood was returned to a vein. Modern dialysis techniques apply a surgical SHUNT between the artery and the VEIN in the wrist for repeated access to apply “artificial kidney” mechanism (see [Figure K.52](#)).



Figure K.52 Kolff kidney.

Kondo, Jun (1930–)

[computational, electronics, quantum, solid-state] Theoretical physicist from Japan. Researcher in the anomalous behavior of electron clouds with respect to CONDUCTOR lattice impurities, specifically providing a detailed understanding of the thermal effects on conduction, leading to highly accurate THERMOCOUPLE design (see [Figure K.53](#)).



Figure K.53 Jun Kondo (1930–). (Courtesy of National Institute of AIST [Advanced Industrial Science and Technology], Tsukuba, Ibaraki, Japan.)

K

Kondo effect

[electronics, quantum, solid-state] Temperature effects pertaining to material properties such as thermal parameters, electrical properties, and MAGNETIC conditions in nonmagnetic metals that have imbedded minute magnetic impurities. This phenomenon was established by JUN KONDO (1930–) in 1964. Alloys of certain materials used as thermocouples are examples of this phenomenon, chromium and manganese DOPING of copper or silver provide a mechanism for measuring temperature based on RESISTANCE. The thermal response to resistance becomes more pronounced at specific temperature that is linked to the Fermi ENERGY of the alloy structure in question, the KONDO TEMPERATURE. Alloys can use the following nonmagnetic base metals such as gold, silver, copper, magnesium, aluminum, and zinc, respectively, with a doping of the following metals, but not limited to IRON, cobalt, manganese, vanadium, TITANIUM, chromium, or nickel. Each doping interface has a specific temperature range and sensitivity (i.e., RESOLUTION), such as the Chromel–Alumel juncture, one of the premier examples of thermocouples. In the 1930s, the Kondo effect was observed primarily at temperatures approaching ABSOLUTE ZERO, while in the 1960s the same principles appeared to apply for temperatures well exceeding the room temperature conditions for the right alloy structures. The Kondo effect exhibits a logarithmic decrease in conductivity with decreasing temperature. Other material properties also display anomalous

behavior for these material structures when approaching the Kondo temperature, such as heat capacity (c_p ; c_p) and MAGNETIC SUSCEPTIBILITY (χ_{mag}) (see Figure K.54).

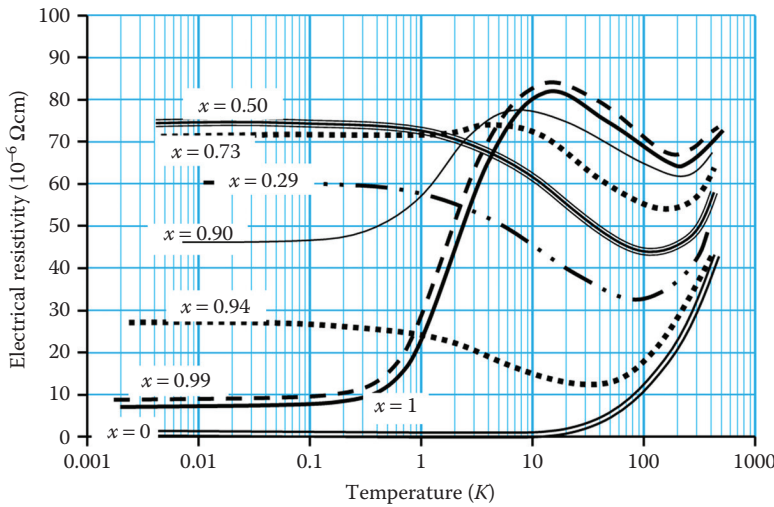


Figure K.54 Illustration of the resistivity as a function of temperature under the Kondo effect for the rare earth cerium (Ce) alloy compound $\text{La}_{1-x}\text{Ce}_x\text{Cu}_6$, as a function of composition “ x ”.

Kondo temperature

[electronics, quantum, solid-state] $T_K \approx \epsilon_F J_{\text{exch}}^{1/2} \exp(-1/nJ_{\text{exch}})$, where ϵ_F is the Fermi ENERGY of the metal LATTICE structure (pertaining to the kinetic ENERGY of the free electrons), J_{exch} is the EXCHANGE INTERACTION between the DOPING ATOM and the free electrons in a CONDUCTOR metal base, and n the number of QUANTUM states.

Koopman’s theorem

[chemistry, computational, solid-state] In a one-dimensional, one-electron atomic model the eigenvalues for the ENERGY for the free electron exchange energy are given as the one-electron IONIZATION ENERGY, making this a limited binary system. Koopmans’ theorem in particular describes the removal of an electron from any of the available molecular electron orbits, hence forming a positive ION and can define the ionization energy for the process. In most other approximations the energy is defined by transition states, pertaining to the electron SHELL MODEL. Named after Tjalling Charles Koopmans (1910–1985) from the Netherlands, who introduced the concept in 1934 and received the Nobel Prize in Physics in 1975.

Köppen climate classification

[geophysics, general] Systematic classification process with categories of major climate and subcategories describing seasonal variations. This system was devised by a Prussian (German) climatologist Wladimir Köppen (1846–1940) in 1884. The five main categories are (1) tropical, (2) dry, (3) mid-latitude with mild winters, (4) mid-latitude with severe winters, and (5) polar. The subcategories are divided in severity and period of rainfall (summer/fall/winter/spring), as well as general state of HUMIDITY next to coldest and warmest episodes, primarily pertaining to the polar climate. A third tier class in this system scale the peak and average temperature distribution (mean annual temperature; warm/cold summer, and combinations of warm/cold seasons) in the respective region outlined under the first and connected consecutive second class. One full-scale classification would, for instance, be mid-latitude with severe winters, severe dry winters, and hot summer season (see Figure K.55).

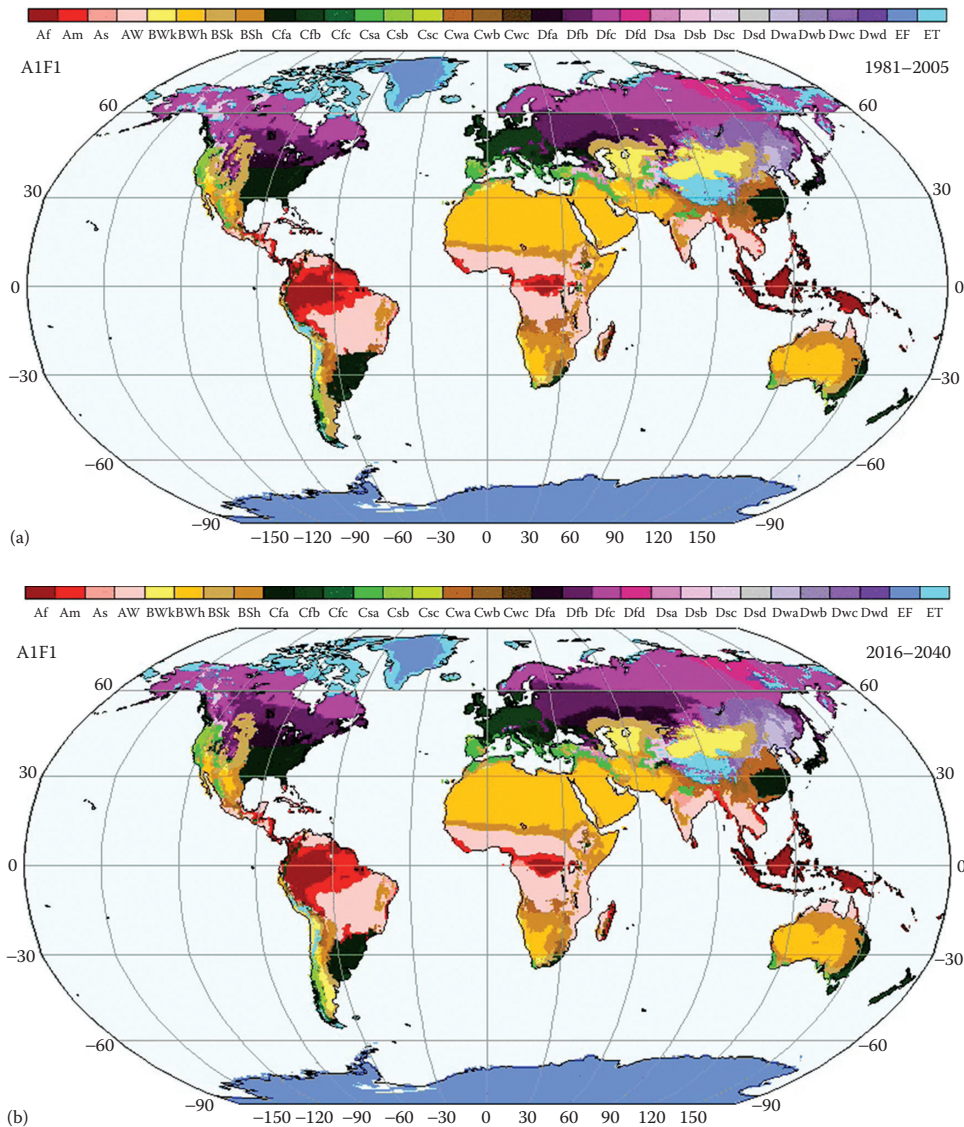


Figure K.55 Example of the Köppen Climate Classification for the years 1981 (a) and 2016 (b) in comparison, illustration of the “global warming.” Group A: tropical/megathermal climates; Group B: dry (arid and semiarid) climates; Group C: temperate/mesothermal climates; Group D: continental/microthermal climates; and Group E: polar and alpine climates. The subclassification is rather convoluted and changes with the main category. Subclassifications; second letter: “W”: desert or “w”: dry winter, “S”: steppe or “s”: dry summer, and additionally “f” signifies abundant precipitation in all seasons. The third letter (sometimes the second letter) denoting temperature. Originally, the indicator “h” represented low-latitude climate (climate with an average annual temperature exceeding 18°C), and the indicator “k” was used to describe a middle-latitude climate (climate average annual temperature never exceeding 18°C). Alternatively, “h” is to use to describe the coldest month average temperature exceeding 0°C, whereas “k” indicates at least one month has a temperature average below 0°C. Additionally, “a” defines the warmest month with an average temperature above 22°C and at least four months above 10°C average, “b” describes the warmest month with an average below 22°C, and in addition at least four months with an average temperature exceeding 10°C, and finally “c” defines a climate condition where three or fewer months out of the year are above an average temperatures of 10°C. (Courtesy of Dr. Markus Kottek, Carinthian Government, Carinthian Institute for Climate Protection [KIKS], A-Klagenfurt am Wörthersee, Austria, and Dr. Franz Rubel, University of Veterinary Medicine Vienna, Institute for Veterinary Public Health, Vienna, Austria; After Rubel, F. and M. Kottek, 2010: Observed and projected climate shifts 1901–2100 depicted by world maps of Köppen-Geiger climate classification. *Meteorol. Z.*, 19, 135–141.)

Korotkoff, Nikolai Sergeyevich

See NIKOLAI SERGEYEVICH KOROTKOV.

Korotkoff sounds

[acoustics, biomedical, fluid dynamics] Sounds produced as a result of a restriction in lumen of a FLOW passage under the influence of a periodic pressure profile. Specifically, the cuff of a SPHYGMOMANOMETER wrapped around the upper arm is pressurized to close-off the BLOOD flow through the brachial artery that is accessible in the antecubital space of the elbow (the crease of the elbow). The flow through the artery can be observed with the assistance of a statoscopes or MICROPHONE. First, the applied pressure from the cuff closes off the blood flow, after which the pressure is gradually released to the point where the pressure in the vessel during systole matches the applied external pressure, from this point on with reducing cuff pressure the blood will intermittently flow through a narrow spacing, acting as a reed in a flute. The short squirts of blood generate an OSCILLATION and inherent TURBULENCE at the compressed oval opening when the intervascular pressure briefly exceeds the externally applied pressure. The mechanical VIBRATION resulting from the forced passage generates an audible acoustic sounds, referred to as the Korotkoff sound, named after the person that recognized its usefulness, NIKOLAI SERGEYEVICH KOROTKOV (1874–1920). Under diagnostic conditions the pressure applied to the cuff is reduced at a rate that allows for a certain level of RESOLUTION in pressure detection depending on the operator or electronic device. The sounds initiate at the point when the applied pressure reaches the SYSTOLIC PRESSURE and when the pressure drops further it will pass the point of diastole, from where the blood will flow freely and the sounds at the pinched lumen cease (sometimes also found as: “Korotkov”) (see [Figure K.56](#)).

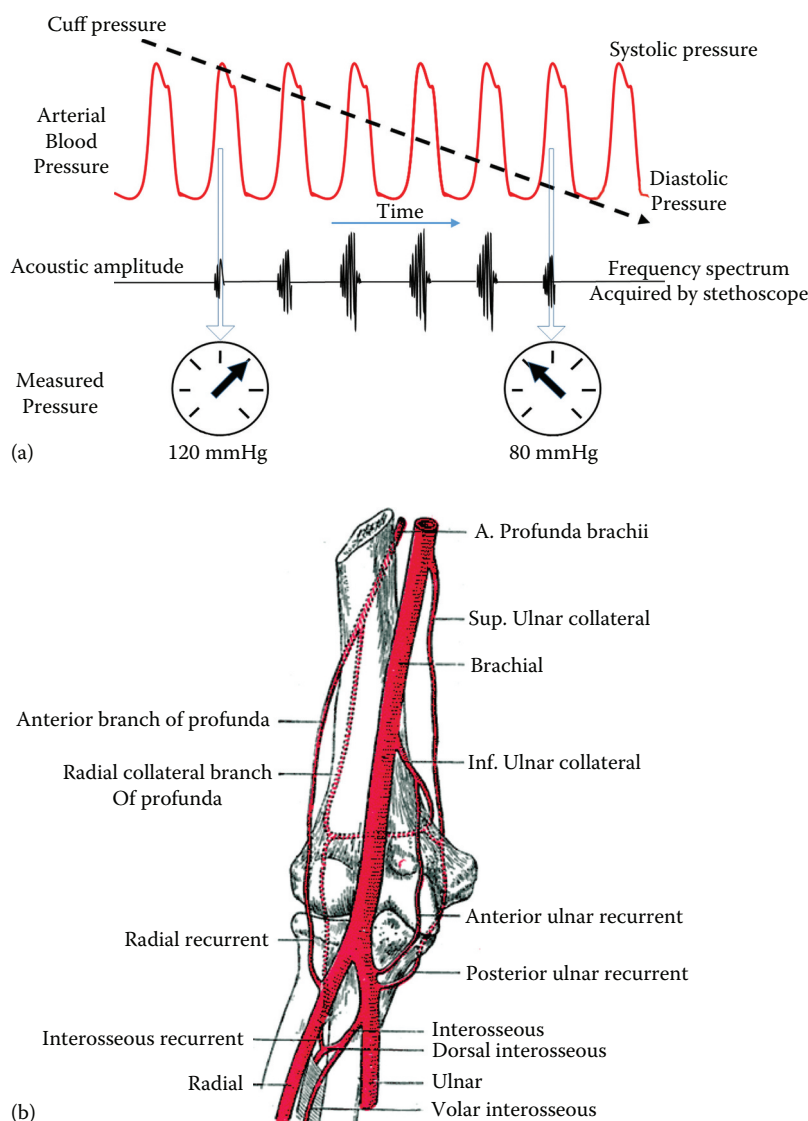


Figure K.56 (a) Illustration of the onset and disappearance of the Korotkov sounds as a function of the diminishing pressure applied on the brachial artery in the elbow by means of a pressure cuff and (b) outline of the arteries in the arm near the elbow.

Korotkov, Nikolai Sergeyevich (Николай Сергеевич Коротков) (1874–1920)

[acoustics, biomedical, fluid dynamics] Physician and surgeon in what was at the time known as Russia, later named the Union of Soviet Socialist Republics (USSR) and at present known again as Russia. Korotkov is known for his invention of the auscultatory method for the determination of arterial BLOOD PRESSURE by listening for SOUND from the blood being squeezed through a narrow ORIFICE obtained from

local compression of the vessel as introduced in 1905 and later in detail in Korotkov's thesis in 1910 (see Figure K.57).



Figure K.57 Nikolai Sergeevich Korotkov (1874–1920) in 1900.

Korteweg–de Vries equation

[acoustics, computational, fluid dynamics, mechanics] Mathematical function for one-dimensional waves ($f(x, t)$; which can describe pressure or displacement, or other wave-dependent parameters) that allows for minor nonlinearities and trivial DISPERSION for a wide bandwidth FREQUENCY SPECTRUM as a SOLUTION to the differential equation: $[df(x, t)/dt] + 6f(x, t)[df(x, t)/dx] + [d^3f(x, t)/dx^3] = 0$. For a solitary wave the solution is $f(x, t) = 2c_1^2 \text{sech}\{c_1(x - 4c_1^2t - x_0)\}$, where c_1 and x_0 are constants. Further implications are in the superposition principle, where two wave interfere elastically, however where the dispersion makes the PHASE VELOCITY of both waves match up after traveling a characteristic asymptotical DISTANCE. The solitary wave solution is also called a SOLITON, representing a WAVE that acts as if it is a PARTICLE. (Note: A PHOTON is sometimes referred to as a “wavicle” to describe the particle-like behavior during reflection and certain SCATTERING conditions.) The equation was defined by Diederik Johannes Korteweg (1848–1941) and GUSTAV DE VRIES (1866–1934) in 1895. The Korteweg–de Vries equation can under certain conditions be considered a special case of the Wentzel–Kramers–Brillouin solution method. Also found as KdV equation.

Korteweg–de Vries–Burgers wave equation

[computational, fluid dynamics, mechanics] The Korteweg–de Vries–Burgers equation describes a mathematical model for a nonperiodic SHOCK WAVE. This is based on the work by JOHANNES MARTINUS (JAN) BURGERS (1895–1981) in 1948 which describes weak acoustic burst waves (solitary wave) as a SOLUTION to his expression: $[df(x, t)/dt] + c_1'f(x, t)[df(x, t)/dx] = c_2'[d^2f(x, t)/dx^2]$, which is combined with the Korteweg–de Vries equation. The Korteweg–de Vries–Burgers equation is defined as: $[df(x, t)/dt] + c_1f(x, t)[df(x, t)/dx] - c_2[d^2f(x, t)/dx^2] + c_3[d^3f(x, t)/dx^3] = 0$, where the term $c_2[d^2f(x, t)/dx^2]$ represents viscous dissipation, and c_i are constants. When the term $c_3 = 0$ this represents Burgers' equation.

Kossel, Walther Ludwig Julius (1888–1956)

[general] Physicist from Germany. Kossel worked on X-RAY diffraction and atomic spectra as well as crystal analysis. His contributions are in theory of the chemical bond, next to the atomic spectra described in the

Sommerfeld–Kossel displacement law, the KOSSEL EFFECT, and the Kossel–Stranski model for crystal growth (see [Figure K.58](#)).



Figure K.58 Walther Ludwig Julius Kossel (1888–1956), 1928.

Kossel effect

[atomic, optics] Crystalline structure analysis with specific applications to semiconductor design and controls based on X-RAY diffraction analysis. The Kossel effect describes the REFLECTION pattern based on the Bragg law for crystalline plane spacing resulting in an isotropic emission pattern. In the reflection/BACKSCATTER profile one can recognize the grouping of diffracted RADIATION in CONES. The geometrical pattern of conic sections captured as lines on a flat film can be defined based on the Kossel cone with half APERTURE ANGLE derived as $\sin(\theta_B) = n(\lambda/2)d_{\text{crystal}}$, where θ_B is the Bragg angle, λ the wavelength of the probing X-ray radiation, n the order of the reflection, captured at intervals, $n = 0$ representing the zeroth-order reflection diffraction (directly above the point of incidence), and d_{crystal} the crystal plane spacing constant. This phenomenon was described by WALTHER LUDWIG JULIUS KOSSEL (1888–1956) (see [Figure K.59](#)).

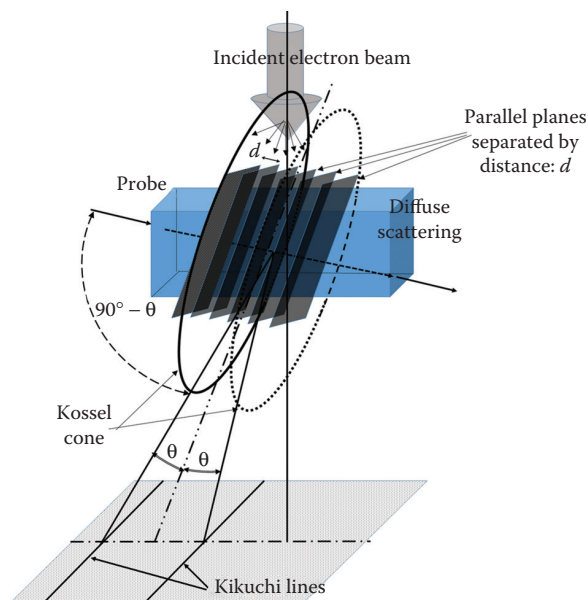


Figure K.59 Graphical representation of the Kossel effect.

Kottler, Friedrich (1886–1965)

[astrophysics, computational, optics] Austrian physicist, primarily focused on theoretical PHYSICS with an interest in ASTROPHYSICS. The work of Kottler in refraction OPTICS by means of relativistic approach was unique in its efforts. Other computational work of Kottler was in theory of relativity applied to GRAVITATION. He is most known for his SOLUTION to the Schwarzschild EQUATION OF RADIATIVE TRANSFER (introduced by KARL SCHWARZSCHILD [1873–1916], for the theoretical description of electromagnetic WAVE propagation through galactic dust) published in 1918. The solution does not account for the light transportation in black holes, thus avoiding accounting for the VACUUM FIELD EQUATIONS as defined by ALBERT EINSTEIN (1879–1955) (see [Figure K.60](#)).



Figure K.60 Friedrich Kottler (1886–1965).

Kramers, Hendrik Anthony (Hans) (1894–1952)

[computational, general, optics] Physicist and mathematician from the Netherlands. Hans Kramers is most known for his contributions to function analysis and in particular the KRAMERS–KRONIG RELATIONS (see Figure K.61).

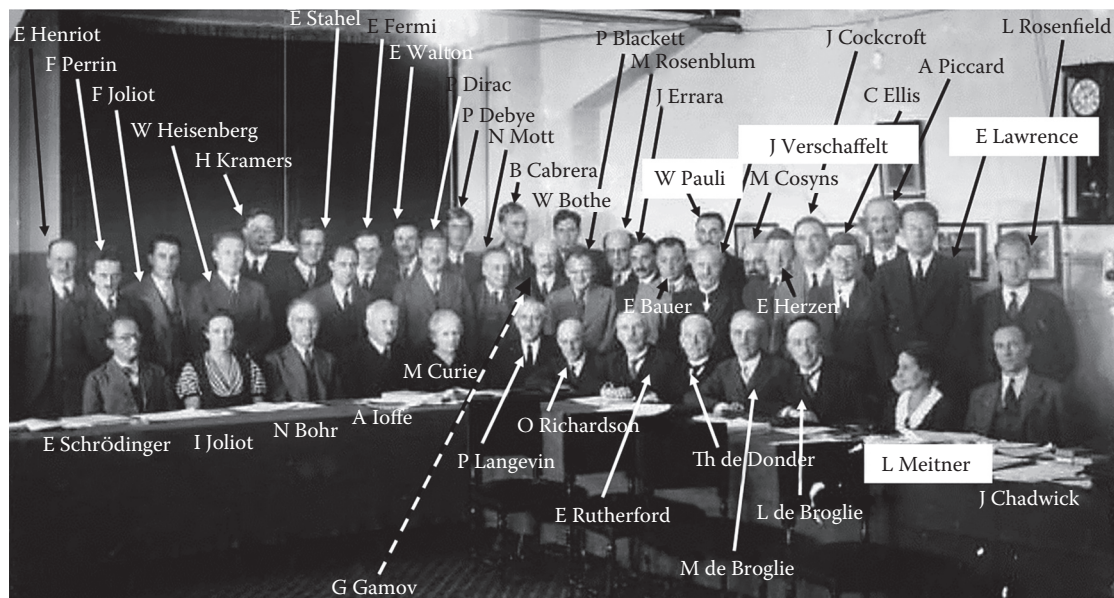


Figure K.61 Hendrik Anthony (Hans) Kramers (1894–1952) at the 1933 Solvay Conference ([Structure et propriétés des noyaux atomiques → Structure & properties of the atomic nucleus; Chair: Paul Langevin], standing, fifth from the left.)

Kramers–Kronig relations

[computational, general, optics] Mathematical relations connecting the real and imaginary parts of any complex function specifically in the imaginary part of the reference frame that has a positive value. The function can be represented by a converging power series. The relations use a complex definition ($f(\varpi) = f'(\varpi) + if''(\varpi)$, where $f'(\varpi)$ and $f''(\varpi)$ are both real), which is as follows: $f'(\varpi) = \mathbb{P}^* / \pi \int_{-\infty}^{\infty} f''(\varpi') / (\varpi' - \varpi) d\varpi'$ and $f''(\varpi) = -\mathbb{P}^* / \pi \int_{-\infty}^{\infty} f'(\varpi') / (\varpi' - \varpi) d\varpi'$, where $\mathbb{P}^*$ is the Cauchy principal value and ϖ a complex variable, with ϖ' a SINGULARITY that is circumvented. The relation is named after RALPH KRONIG (1904–1995) and HENDRIK ANTHONY (HANS) KRAMERS (1894–1952). One specific example of a function is the pulse response function to an impulse applied at time (t'); providing the functional response of a phenomenon as $f(t - t')$. Another application can be used to solve for the index of REFRACTION.

Krebs cycle

[biomedical, chemical, thermodynamics] GLUCOSE breakdown reaction mechanism in biological systems. Also known as the citric ACID cycle, or tricarboxylic acid cycle (TCA cycle). All aerobic organisms rely on the Krebs cycle, which consists of a series of chemical reactions to generate CHEMICAL ENERGY in the form of ADENOSINE TRIPHOSPHATE. The OXIDATION process involves the conversion of acetate derived from nutrients such as carbohydrates, lipids as well as proteins. In addition, the Krebs cycle creates the building blocks of

certain amino acids. It has central importance to many biochemical pathways suggesting a rudimentary component of cellular METABOLISM (see [Figure K.62](#)).

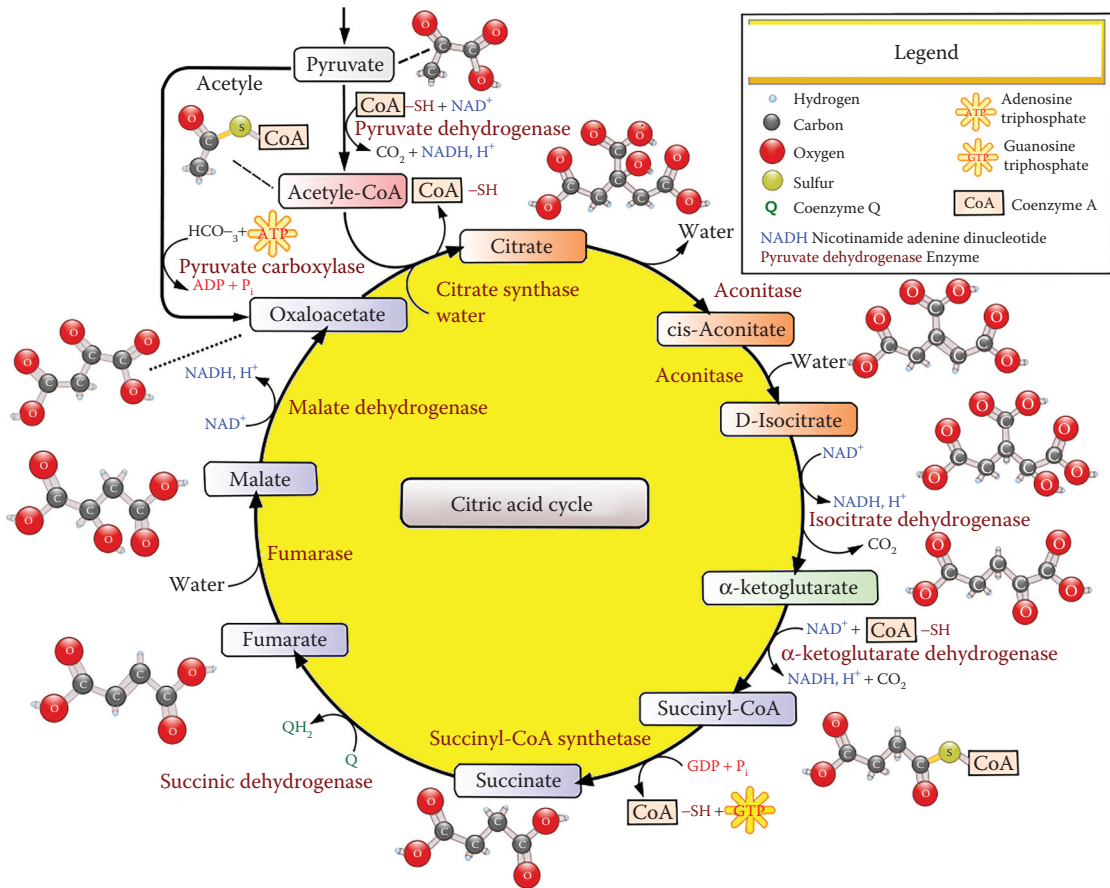


Figure K.62 Diagram of the Krebs cycle process in the renewable energy process for adenosine triphosphate and associated metabolism.

Krimholtz–Leedom–Matthaei (KLM) transducer model

[acoustics, computational, nuclear] Electroacoustic TRANSDUCER finite-element computer modeling tool and piezoarray modeling tool. Computer simulation mechanism to generate the beam shape and intensity pattern as a function of angular position as produced by a piezoelectric array. A pressure (i.e., AMPLITUDE squared) as a function of voltage distribution based on an analog electronic circuit design that mimics the acoustic transducer. The model calculates the force as a result of the applied electrical field in a piezocrystal and associated velocity of “PARTICLE” displacement.

Krogh, Schack August Steenberg (1874–1949)

[biomedical] Scientist and zoologist from Denmark. Krogh performed research in the respiratory mechanism as well as CAPILLARY function in the PERFUSION of organs. Krogh received the Nobel Prize in Physiology

in 1920 for his work on the regulation mechanism of capillary GAS and ionic exchange; the capillary MOTOR. He is one of the founding fathers of exercise science (see [Figure K.63](#)).



Figure K.63 Schack August Steenberg Krogh (1874–1949). (Courtesy of George Grantham Bain collection, the United States Library of Congress's Prints and Photographs division under the digital ID ggbain.32006.)

K

Krogh tissue cylinder model

[biomedical, fluid dynamics] Model approach for molecular exchange in vascular flow, developed by SCHACK AUGUST STEENBERG KROGH (1874–1949). In order to establish the DIFFUSION between CAPILLARY FLOW and the surrounding bulk tissue, the tissue is considered over a short length (ℓ) along the vessel only, in cylindrical symmetry. Exploring the tissue diffusion with chemical reaction rate (binding to ligands). (*Note:* Not to be confused with free FLOW diffusion rate.) R_i in radial (r) direction only for a vessel with radius R_0 , the individual ($\square$) molecular transfer (N_i) of solutes with respective concentrations $[C_i]$ obeys the following conservation law (CONSERVATION OF MASS): $(\partial[C_i]/\partial t)2\pi r\ell\Delta r = \{N_{ir} - N_{ir+\Delta r}(r + \Delta r)\}2\pi\ell + R_i2\pi r\ell\Delta r$. Combining the conservation of mass with the Fick's diffusion law: $N_{ir} = D_{AB}(\partial[C_i]/\partial r)$, where D_{AB} is the DIFFUSIVITY of the SOLUTE that can be solved under certain confined boundary conditions. For oxygen often the diffusion reaction rate is considered to be constant: $R_{O_2} = -c''$, while assuming virtual steady-state conditions during the transfer from BLOOD hemoglobin to tissue hemoglobin, or free tissue oxygen. The Krogh tissue cylinder now holds the oxygen exchange from artery ($\square$) to tissue ($\square$): $[C_{O_2}]_a = [C_{O_2}]_t + (c''/D_{AB})[(r^2 - R_t^2)/4] + (c''/D_{AB})(R_t^2/4)\ln(R_t/r)$, with R_t the radius of the Krogh cylinder.

Krogh's diffusion coefficient (K_{Diff})

[biomedical, chemical] The DIFFUSION coefficient in LIQUID phase: $K_{\text{Diff}} = \alpha_{\text{sol}}D_{\text{diff}}$, where α_{sol} is the solubility (Henry's law coefficient), and D_{diff} the diffusion coefficient is GAS PHASE.

Kronecker, Leopold (1823–1891)

[computational] Mathematician from the Prussian Empire (now Poland). Kronecker introduced several basic formulations, including the “delta function,” also known as the KRONECKER DELTA FUNCTION (δ) (see Figure K.64).



Figure K.64 Leopold Kronecker (1823–1891), 1865.

Kronecker delta function (δ)

[biomedical, computational, engineering] Function used to selectively isolate certain aspects of a phenomenon as a function of unique locations in time or position. The delta function is defined by two parameters: i and j for which if these equal the function 1, otherwise zero; $\delta_{i,j}$, with $\delta_{i,j} = 1$ for $i = j$ and $\delta_{i,j} = 0$ for $i \neq j$. The existence follows from the summation: $a_n = \sum_i \delta_{i,n} a_i$. In comparison the DIRAC DELTA FUNCTION uses integration: $f(x_0) = \int f(x) \delta(x - x_0) dx$. Another use for the Kronecker delta is in vector and TENSOR analysis for determination of matrix coefficients for a transformation between the merates of a contravariant vector χ^i in a coordinate system referred to as unprimed (x^i) with respect to the contravariant vector (χ'^i) in the primed coordinate system (x'^i). The transformation is defined by equations that are partial derivatives of the base point coordinates ($\partial x'^i / \partial x^j$), while forming a linear homogeneous relationship, giving $\chi'^i = (\partial x'^i / \partial x^j) \chi^j$, respectively the transform for the covariant vector: $\zeta'_j = (\partial x^j / \partial x'^i) \zeta_i$, where the coefficients are linked by the Kronecker delta as: $(\partial x'^i / \partial x^j) (\partial x^j / \partial x'^i) = \delta^j_j$ (also Kronecker symbol) (see Figure K.65).

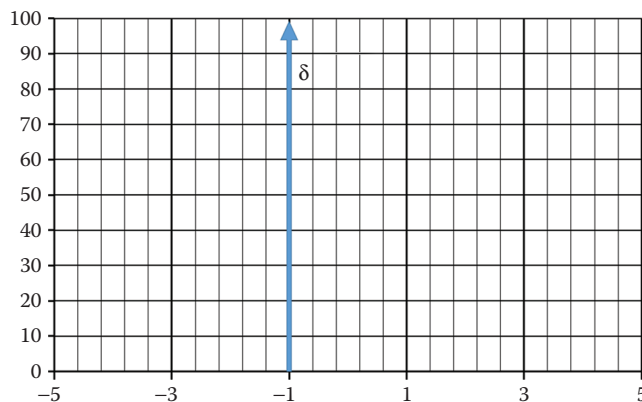


Figure K.65 Graphical representation of the Kronecker delta function.

Kronig, Ralph (1904–1995)

[computational, general, optics, quantum] Physicist from Germany. In 1925 Kronig introduced the idea that an electron spins around its axis, creating a MAGNETIC moment. The electron-spin idea was suggested in 1921 by ARTHUR HOLLY COMPTON (1892–1962), in the format of a perceived GYROSCOPE, but he did not implement this model (see [Figure K.66](#)).



Figure K.66 Ralph Kronig (1904–1995).

Kronig–Penney model

[quantum, solid-state] Idealized crystal structure reduced to a one-dimensional model encompassing all the features of any specific real crystal. The electron potential in this model is a one-dimensional function only ($V(x)$), with well-defined potential wells; wells with width w , spacing d , and depth $-V_0$. The electron ENERGY and WAVE function for an electron with mass m_e in this situation can be solved using the SCHRÖDINGER EQUATION. The energy bands in this approximation configuration can thus be defined as: $\sqrt{(2m_e w^2 V_0 / d^2)} = 12.0$ where $d/w = 0.1$, the choice of parameters depends on the original crystalline structure with associated energy configuration.

K-shell internal conversion coefficient (α_{icc})

[nuclear] The rate of INTERNAL CONVERSION (ICC) of electron excitation by means of electron to X-ray RADIATION, expressed as: $\alpha_{conv} = (1/\omega_K) \{[(N_{K,\alpha}/\epsilon_{K,\alpha}) + (N_{K,\beta}/\epsilon_{K,\beta})]/(N_\gamma/\epsilon_\gamma)\}$ = number of electron-electron K-shell de-excitations/number of gamma radiation-electron K-shell de-excitations, where ω_K is the K-shell FLUORESCENCE yield, $N_{K,\alpha}$ is the number of K_α X-ray emissions (i.e., height of peak in spectral profile), N_γ the GAMMA RAY emissions from the RADIOACTIVE ISOTOPE itself, $\epsilon_{K,\alpha}$ the “efficiency” of the detection of the K_α X-ray emissions, $N_{K,\beta}$ is the number of K_β X-ray emissions, and $\epsilon_{K,\beta}$ the “efficiency” of the detection of the K_β X-ray emissions. Conversion in this case means the match of electron WAVE function

(in relativistic approach) and associated MAGNETIC and electric transition ENERGY, with respect to the gamma energy. Electric and magnetic fields are generated due to the brief period on NUCLEON rearrangement under external forces. During this electromagnetic interaction the NUCLEUS emits gamma rays, and the energy can be transferred to atomic electrons, which can excite the electrons in the high-energy *K*-shell. The conversion is mainly the result of the time-varying Coulomb field of the nucleus. For large atomic number (*Z*), the relativistic approach becomes more important, with large deviations from the classical approach. In most cases a look-up table is used or computer programs for estimation to determine the specific threshold values for the gamma energy to reach conversion. For verification of the methodology measurements with a SOLENOID beta-ray spectrometer combined with X-RAY spectral analysis can provide QUANTIFICATION (*also see INTERNAL CONVERSION and K-SHELL*).

Kurie plot

[nuclear] In nuclear RADIOACTIVITY the plot of the beta RADIATION spectra by means of plotting the FERMI FUNCTION ($F_f(Z_D, p_e)$) against the kinetic ENERGY of the electron ($KE_e = (1/2)m_e v^2$). Considering that electron emission requires a relativistic approach based on the PARTICLE velocities. The full function for the spectral DECAY is $\Lambda(p_e) p_e - F_f(Z_D, p_e) p_e^2 \left\{ KE_e^{\max} - KE_e \right\}^2 \delta p_e \left(|\mathcal{M}_{fi}|^2 / 2\pi^3 c^2 \hbar^7 \right)$, where $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ the Planck constant, $p_e = m_e v$ the electron momentum for charge with mass m_e , and velocity v for ELEMENT with atomic number *Z* (number of protons), $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of light, and $\mathcal{M}_{fi} = V_{fi} / g_f = \int \Psi_D^*(\vec{r}_1, \vec{r}_2, \dots, \vec{r}_A) \Psi_e^*(\vec{r}_e; Z) \Psi_{\bar{\nu}}^*(\vec{r}_{\bar{\nu}}) \times V_{\text{int}} \Psi_p(\vec{r}_1, \vec{r}_2, \dots, \vec{r}_A) d\vec{r}_1 d\vec{r}_2 \dots d\vec{r}_A d\vec{r}_e d\vec{r}_{\bar{\nu}}$ the interaction matrix element, with “strength” $g_f = 8.8 \times 10^{-5} \text{ MeV fm}^3$ of the beta decay process, V_{fi} is the expectation value, represented by the matrix element of the transition operator *V*, which is tied to the wave function (Ψ) of the PARENT NUCLEUS (see Figure K.67).

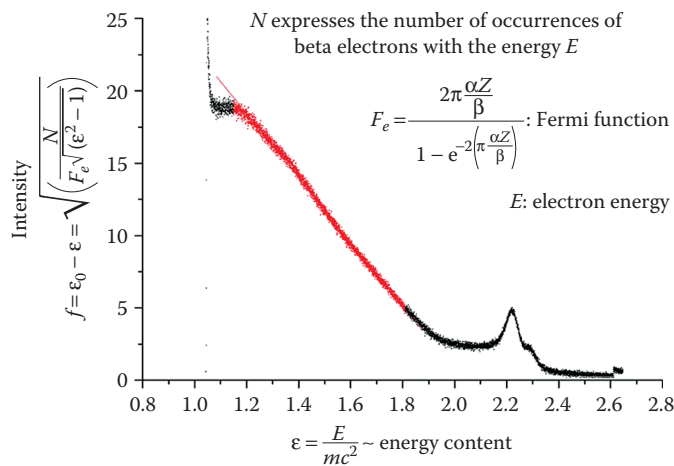


Figure K.67 Kuri plot for the electroweak interactions beta decay process. For instance, in the decay process one of the down quark neutrons is converted to an up quark, which will be converted from a neutron into a proton. During this process a W^- boson is also emitted, which subsequently decays into an electron and an electron–antineutrino pair. Generally, this process can best be described using Feynman diagrams.

Kutta, Martin Wilhelm (1867–1944)

[fluid dynamics] Scientist and mathematician from Prussia (Poland). Kutta provided NUMERICAL analysis mechanisms for solving complex differential equations. His work aided in the expedited development of AERODYNAMICS, specifically in collaboration with NIKOLAY ZHUKOVSKY (1847–1921) (see [Figure K.68](#)).



Figure K.68 Martin Wilhelm Kutta (1867–1944).

Kutta condition

[fluid dynamics] The fact that under fluid flow viscosity is required, providing a condition that makes FLOW execute a smooth finish when detaching from a trailing edge of a body that is subjected to LIFT conditions, such as a wing. This outlines the lifting flow conditions. Based on the FLUID DYNAMICS work of MARTIN WILHELM KUTTA (1867–1944) (see [Figure K.69](#)).

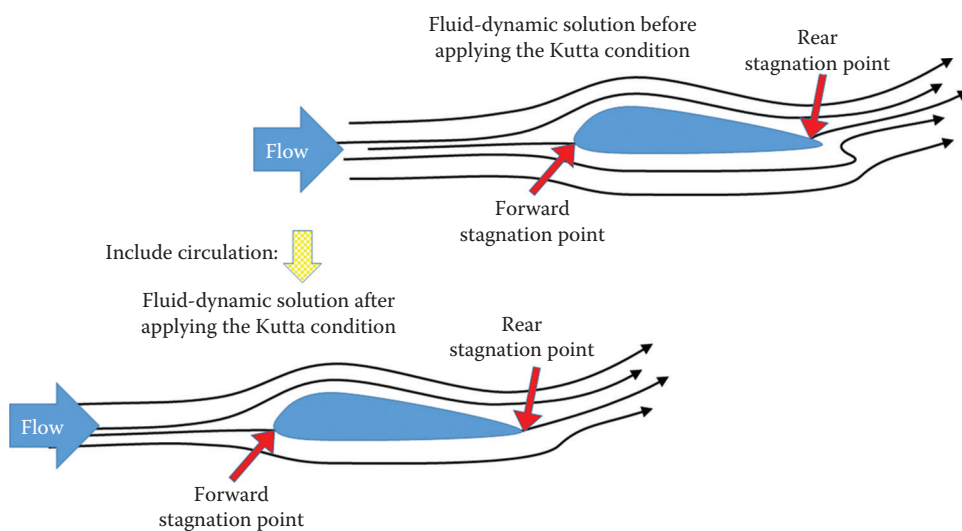


Figure K.69 Graphical representation of the Kutta condition that eliminates the computational conundrum for the calculation providing the conditions for lift by means of incorporating circulation in the flow.

Kutta lift

[fluid dynamics] See **MAGNUS LIFT**.

Kutta–Joukowski equation

[fluid dynamics] Aerodynamic principle introduced by MARTIN WILHELM KUTTA (1867–1944) and NIKOLAY JOUKOWSKY (also: Zhukovsky) (1847–1921) in the early 1990s. The theory described the lift generated by the movement of a cylinder, in horizontal alignment, through a FLUID. The LIFT was found to be a function of the following parameters: relative velocity between the fluid and the cylinder (v), the density of the fluid (ρ), and the CIRCULATION (Γ_{circ}). The lift (L_{lift}) is also related to the Bernoulli principle (with pressure P) and yields $L_{\text{lift}} = \ell_{\text{chord}} \Delta P = -\rho v \Gamma_{\text{circ}}$, where ℓ_{chord} is the length of the chord of the object in flight, in this case the half circumference of the cylinder. Circulation is, in approximation, the closed loop integral of the tangential fluid velocity (also **KUTTA–ZHUKOVSKY EQUATION**).



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L (angular momentum)

[mechanics, nuclear] For a rigid body with respective mass constituents (m_i) with momentum $\vec{p}$, at respective radii with the axis of rotation ($\vec{r}_i$) and local velocities ($\vec{v}_i$) yields $L = \vec{r} \times \vec{p} = \sum_i \vec{r}_i \times m_i \vec{v}_i = I\omega$, where I is the MOMENT OF INERTIA and ω the ANGULAR VELOCITY. In nuclear PHYSICS the NUCLEAR ANGULAR MOMENTUM is defined by the angular momentum quantum number, combining the electronic angular momentum and the nuclear angular momentum to provide the TOTAL ANGULAR MOMENTUM for the atomic configuration. The nuclear ORBITAL ANGULAR MOMENTUM $L = \sqrt{\ell(\ell+1)}\hbar$, where $\ell = 0, 1, 2, \dots, n-1$ (n the PRINCIPAL QUANTUM NUMBER) is the angular quantum number, defining the configuration of the spherical harmonic functions as solutions to the SCHRÖDINGER EQUATION. In reference, the nuclear angular momentum is $I = \sqrt{i(i+1)}\hbar$ (i.e., the PROTON spin; $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant) with nuclear angular quantum number i ; the electronic angular momentum is $J = \sqrt{j(j+1)}\hbar$, with $j = \ell \mp (1/2)$ the total angular momentum quantum number. The nuclear angular momentum combines with the electronic angular momentum to provide the total angular momentum $\vec{F} = \vec{I} + \vec{J}$. Note that in this case F does not refer force, the convoluted use of parameters is due to the specificity of the fields. The same selection rules and coupling rules apply to electronic and nuclear angular momentum as to the coupling between the total angular momentum S and the orbital angular momentum L (see Figure L.1).



Figure L.1 The use of angular momentum to preserve balance during for instance skating and break-dancing and hence reducing the requirements of muscular force.

$L(\vec{r}, \vec{s}, t)$

[astrophysics/astronomy, nuclear, optics] Radiance is the MAGNITUDE of ELECTROMAGNETIC RADIATION within a cone of specific SOLID ANGLE of radiated ENERGY emerging from a source, in direction $\vec{s}$ observed at location $\vec{r}$ as a function of time t , that is incident on a surface area; unit $[\text{W}/\text{m}^2\text{sr}]$. The Radiance is derived from the Poynting vector: $\vec{S}, \vec{S} = (\vec{E} \times \vec{B})/\mu$, where $\vec{E}(\vec{r}, \vec{s}, t)$ represents the electric field strength as a

function of time, location and direction, $\vec{B}(\vec{r}, \vec{s}, t)$ is the coupled MAGNETIC FIELD vector, and μ the DIELECTRIC permeability for the medium (dielectric permeability of free space multiplied by the RELATIVE PERMEABILITY of the medium). The RADIANCE ($L(\vec{r}, \vec{s}, t)$) is defined as the time average of the length of the Poynting vector, averaged over one or more cycle lengths: $L(\vec{r}, \vec{s}, t) = (\vec{E} \times \vec{B}) / \mu$. When no external forces act on the system, the energy in the system is conserved. The conservation principle is captured by a general balance equation. The balance equation resembles those used to model chemical reactions. For example, the general energy balance follows the Schwarzschild equation of radiative transfer, expressed as a function of time: $(1/c) [\partial L(\vec{r}, \vec{s}, t) / \partial t] = -\vec{s} \cdot \nabla L(\vec{r}, \vec{s}, t) - (\mu_a(\vec{r}) + \mu_s(\vec{r})) L(\vec{r}, \vec{s}, t) + \mu_s(\vec{r}) \int_{4\pi} P(\vec{s}, \vec{s}') L(\vec{r}, \vec{s}', t) d\varpi' + S(\vec{r}, \vec{s}, t)$. The EQUATION OF RADIATIVE TRANSFER was introduced by KARL SCHWARZSCHILD (1873–1916) in 1906 to describe the propagation of RADIATION from galactic sources through cosmic dust, with additional initial work by SIR ARTHUR SCHUSTER (1851–1934) in 1905 (describing light propagation through a foggy ATMOSPHERE) and FRIEDRICH KOTTLER (1886–1965) in 1918, followed in 1947 by the work of SUBRAHMANYAN CHANDRASEKHAR (1910–1995). The RADIATIVE TRANSFER equation also applied to propagation of light through a smaller turbid medium, such as tissue, to define the laser interaction for biological application. The balance equation describes the accumulation of electromagnetic radiation within a system equals the inflow through the system boundaries minus the outflow through the system boundaries plus the generation of radiation within the system and subtracting the consumption (annihilation) within the system. The system is defined by three MICROSCOPIC terms, representing the attenuation (absorption) $\mu_a(\vec{r})$, SCATTERING $\mu_s(\vec{r})$, and redirection of propagation $P(\vec{s}, \vec{s}')$. A derived parameter is the total attenuation $\mu_t(\vec{r}) = \mu_a(\vec{r}) + \mu_s(\vec{r})$. A second derived parameter is the scattering anisotropy factor (g), which follows for the angular PROBABILITY distribution for scatter as $g = \int_{4\pi} P(\vec{s}, \vec{s}') \cdot (\vec{s}, \vec{s}') d\varpi' = \int_{4\pi} P(\theta) \cos \theta d\varpi'$, θ the ANGLE with the original direction of propagation. The latter is also referred to as the SCATTERING PHASE FUNCTION and is also used in the reduced scattering coefficient, representing the scattering back into the original direction of propagation $\mu_s'(\vec{r}) = (1 - g)\mu_s(\vec{r})$, which can be carried forward to the reduced total attenuation: $\mu_t'(\vec{r}) = (1 - g)\mu_t(\vec{r})$. The equation of radiative transfer defining the radiance is constructed from the “loss” and “gain” components, all considered for a finite small unit of volume. The term $(1/c) [\partial L(\vec{r}, \vec{s}, t) / \partial t]$ represents the rate of change in radiance per unit volume, with c the speed of light. The term $\vec{s} \cdot \nabla L(\vec{r}, \vec{s}, t)$ signifies the loss (minus sign) through the boundaries. The term $(\mu_a(\vec{r}) + \mu_s(\vec{r})) L(\vec{r}, \vec{s}, t)$ indicates the loss (minus sign) of ELECTROMAGNETIC ENERGY in radiance due to attenuation resulting from both absorption and redirected scattering out of the original path of the incident beam. The term $\mu_s(\vec{r}) \int_{4\pi} P(\vec{s}, \vec{s}') L(\vec{r}, \vec{s}', t) d\varpi'$ represents the recovery (gain) of radiance from scattering back into the original direction: $\vec{s}'$ into direction $\vec{s}$ with angular probability distribution $P(\vec{s}, \vec{s}')$. The final term $S(\vec{r}, \vec{s}, t)$ is a source term, either FLUORESCENCE or other means of generating electromagnetic radiation such as a FIBER-OPTIC placed inside a tumor volume (see Figure L.2).



Figure L.2 Representation of $L(\vec{r}, \vec{s}, t)$ radiance.

L characteristic X-rays

[atomic, electromagnetism, nuclear] Class of X-RAY spectral lines as defined by CHARLES GLOVER BARKLA (1877–1944) in 1908. Characteristic lines are a function of the medium used for emission. The characteristic L lines are the second group following the K lines, and followed by M, N, and so on. The L-spectrum belongs to orbital electron transitions from the 2s ENERGY configuration. The emission lines follow the Moseley law (*also see* **K-CHARACTERISTIC X-RAY**) (*see* [Figure L.3](#)).

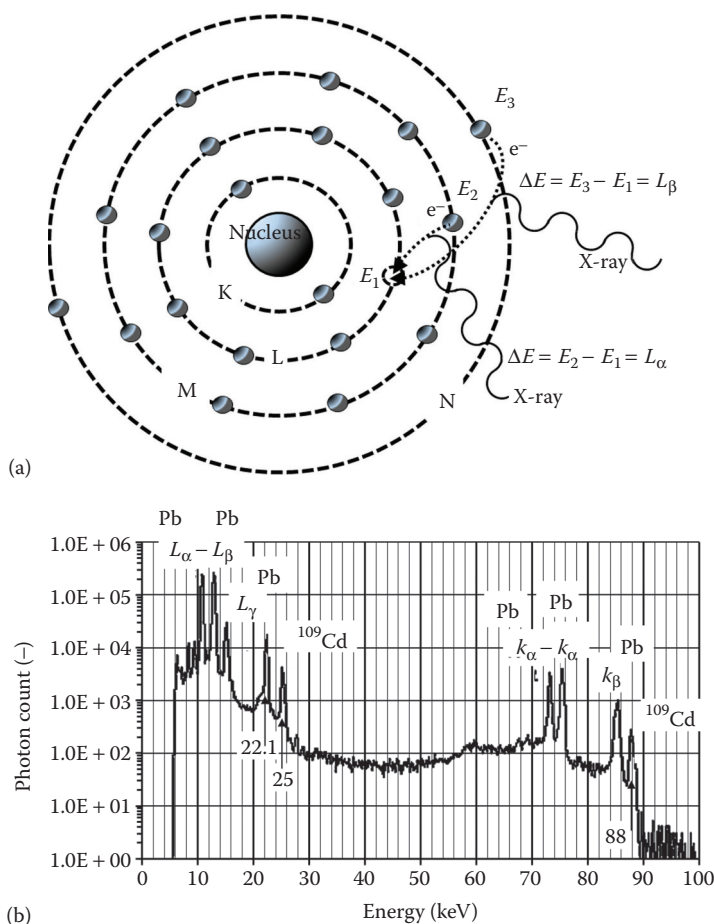


Figure L.3 (a) L line transition. When a vacant spot is generated by primary excitation X-ray or, alternatively, by the previous transition in the L shell, an electron originating from the M shell or the N shell will migrate to occupy the formed vacancy. In this process the transition generates a characteristic X-ray unique to the particular element. As a result a vacancy in the M or N shell is produced, (b) L-characteristic X-ray lines observed in X-ray spectroscopy for the fluorescence of lead (Pb) from cadmium (^{109}Cd).

L series

[nuclear] CHARACTERISTIC X-RAY—L transition (L CHARACTERISTIC X-RAYS), *see* **L-CHARACTERISTIC X-RAYS** (*also see* **LYMAN SERIES**).

La Systeme International d'Unites

[astrophysics, computational, fluid dynamics, general, mechanics, nuclear] See **SI UNITS**.

Lagrange, (Joseph-Louis) Giuseppe Luigi comte de (1737–1813)

[astronomy, computational, electromagnetism, general, quantum, thermodynamics] French/Italian astronomer, scientist, and mathematician, partially during the time of Napoleon Bonaparte (1769–1821). Lagrange was a contemporary of LEONHARD EULER (1707–1783) and JEAN-BAPTISTE LE ROND D'ALEMBERT (1717–1783). Lagrange formulated several definitions of equilibrium for THERMODYNAMICS, FLUID DYNAMICS, and MECHANICS. The work of Lagrange followed on the work of JULES HENRI POINCARÉ (1854–1912) and ALEKSANDR MIKHAILOVICH LYAPUNOV (1857–1918) (see [Figure L.4](#)).

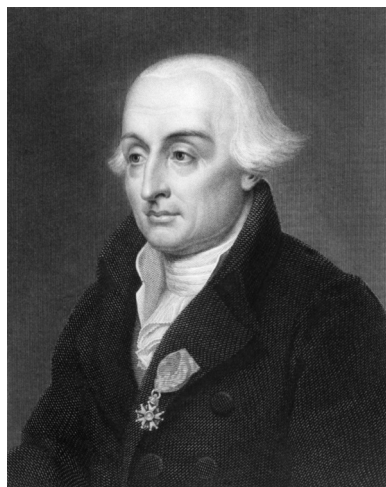


Figure L.4 Giuseppe Luigi comte de Lagrange (Joseph Louis Lagrange) (1737–1813). (Courtesy of R. Hart.)

Lagrangian equations in generalized co-ordinates

[atomic, fluid dynamics, mechanics] Description of points with mass (e.g., particles) under influence of external and/or mutually interactive forces. Generally when HAMILTONIAN MECHANICS is insufficient to describe complex systems, a Lagrangian approach may account for the multitude of DEGREES OF FREEDOM in the ENERGY of the system.

Lagrangian finite strain tensor

[computational, fluid dynamics, mechanics] A measure of the difference between the deformation TENSOR ($C = F^T F$, where F represents the deformation gradient) and ($I = (I_1, I_2, I_3)$) the undeformed configuration location vector; expressed as $E_{LK} = (1/2)(C - I) \sim \nabla \vec{v} + (\nabla \vec{v})^T$ where $\vec{v}$ is the deformation rate or FLOW velocity (solid or FLUID, respectively).

Lagrangian for classical gravitational field

[computational, electromagnetism, general, quantum] $\mathcal{L}_g[\vec{x}, t] = -\mu[\vec{x}, t]Z[\vec{x}, t] - (1/G8\pi)(\nabla Z[\vec{x}, t])^2$, where $Z[\vec{x}, t]$ is the potential of the GRAVITATIONAL FIELD, tying in with the equation of MOTION as $m\ddot{\vec{x}}(t) = -m\nabla Z[\vec{x}(t), t]$ and $\mu[\vec{x}, t]$ is the mass density as a function of the vector location $\vec{x}$ in TIME (t)

Lagrangian form of the hydrodynamical equations

[computational, fluid dynamics] The EQUATIONS OF MOTION of a mass of FLUID applied to flow with respect to local DENSITY (ρ) and PRESSURE (P). The system assumes a “PARTICLE” in the FLOW to be at location (x_1, y_1, z_1) at a point in TIME (t) with respective velocities $(\partial x/\partial t, \partial y/\partial t, \partial z/\partial t)$ and acceleration $(\partial^2 x/\partial t^2, \partial^2 y/\partial t^2, \partial^2 z/\partial t^2)$ under externally applied force with components $(F_x; F_y; F_z)$ provides $\partial^2 x/\partial t^2 = F_x - [(1/\rho)(\partial P/\partial x)]$; $\partial^2 y/\partial t^2 = F_y - [(1/\rho)(\partial P/\partial y)]$; $\partial^2 z/\partial t^2 = F_z - [(1/\rho)(\partial P/\partial z)]$, respectively. Using transformation this provides the Lagrangian hydrodynamic equations: $((\partial^2 x/\partial t^2) - F_x)(\partial x/\partial x_1) + ((\partial^2 y/\partial t^2) - F_y)(\partial y/\partial x_1) + ((\partial^2 z/\partial t^2) - F_z)(\partial z/\partial x_1) + [(1/\rho)(\partial P/\partial x_1)] = 0$; respectively $((\partial^2 x/\partial t^2) - F_x)(\partial x/\partial x_2) + ((\partial^2 y/\partial t^2) - F_y)(\partial y/\partial x_2) + ((\partial^2 z/\partial t^2) - F_z)(\partial z/\partial x_2) + [(1/\rho)(\partial P/\partial x_2)] = 0$; and $((\partial^2 x/\partial t^2) - F_x)(\partial x/\partial x_3) + ((\partial^2 y/\partial t^2) - F_y)(\partial y/\partial x_3) + ((\partial^2 z/\partial t^2) - F_z)(\partial z/\partial x_3) + [(1/\rho)(\partial P/\partial x_3)] = 0$. This applies the Lagrangian method to the principles of flow.

Lagrangian libration point

[computational, geophysics] Location in free space as the “FOCAL POINT” of a space orbit configuration ensuring a position with respect to both the MOON and EARTH simultaneously. The existence of such points in gravitational and orbital mathematics were derived in 1772 by “comte de Lagrange” (GIUSEPPE LUIGI COMTE DE LAGRANGE [1737–1813]), five locations in total: L_1 , L_2 , L_3 , L_4 , and L_5 . These would be orbital locations where a space station can be placed for stable observation. These free space revolving positions are however unstable, especially since the ORBITS of the Moon is oval (see [Figure L.5](#)).

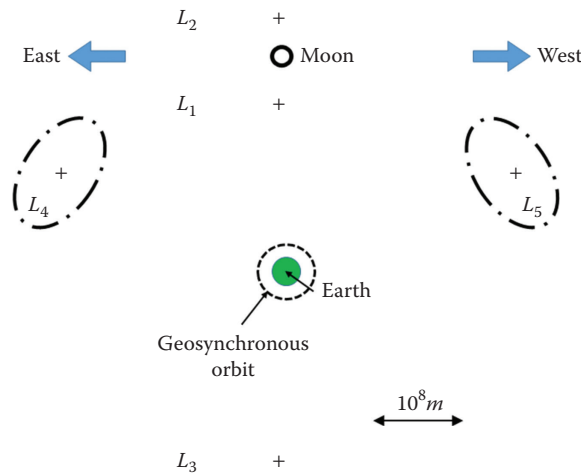


Figure L.5 Lagrange libration points for Moon orbit.

Lagrangian theory

[computational, mechanics, thermodynamics] Mathematical representation of full-featured equation of MOTION dynamics in a system with less than $3k$ DEGREES OF FREEDOM in a set of n independent EQUATIONS OF MOTION for k particles, independent of the number of particles representing the system. This is in contrast to the convoluted Newtonian formulation, where all particles interact with each other and the system needs to be solved. The generalized format is expressed in the following manner: $(d/dt)(\partial T/\partial \dot{\xi}_i) - (\partial T/\partial \xi_i) = \sum_{j=1}^k \vec{F}_j \cdot (\partial r/\partial \xi_i)$, $i = 1, \dots, n$, where $\xi_i = \xi_i(\vec{r}_1, \vec{r}_2, \vec{r}_3, \dots, \vec{r}_k, t)$ is a transformation of the location ($\vec{r}_x$), F_j the independently acting forces on the individual particles culminating in a set of generalized forces.

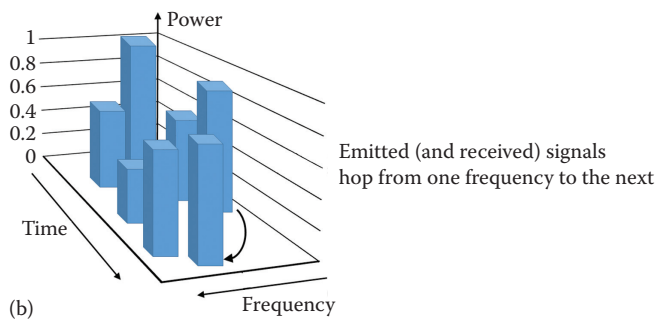
Lamarr, Hedy (1914–2000)

[computational, general, signal] Born: Hedwig Eva Maria Kiesler; female actor and nature philosopher born in Austria, who, together with composer George Antheil [1900–1959], conceived the idea of frequency hopping. The “frequency hopping” concept is a frequency modulation technique that applies to spread FREQUENCY SPECTRUM transmission (frequency hopping spread spectrum: FHSS; based on the conversion of multiple frequencies carrying parts of the total signal/data), preventing any unauthorized receiver to “tune in” to the communication band (i.e., telecommunications jamming). By repeated switching the radio-frequency CARRIER wavelength in a RADIO or telecommunication (e.g., mobile phone) transmission, only a dedicated receiver will be able to continuously acquire the transmitted data. Hedy Lamarr and George Antheil introduced this concept in 1942, during World War II (1940–1945; WW-2). The early mechanism as introduced by Hedy Lamarr was based on musical instruments, specifically the mechanical organ, or player PIANO (pianola), electronic carillon or other various types of orchestrion. The encoding was meant to provide uninterrupted guidance during the launch and trajectory of a torpedo, ensuring, maintaining, and correcting course and guarantee a delivery to the target location. The torpedo should employ a “tuning” role rotating with the same patterns as in the transmitter on the submarine, thus ensuring uninterrupted communications and flawless exchange of information without risk of enemy sabotage prior to striking the target. In comparison to the musical background, the orchestrion (Carillon; barrel organ hurdy-gurdy) uses a role of paper with holes punched in a certain pattern that engage the keys on the instrument for a specific note when the hole passes the trigger switch. The same concept is still applicable to modern spread spectrum frequency communication, such as those applied in cordless telephones, Bluetooth, and WiFi (802.11 wireless internet access). During World War II, the concept encountered much opposition, undoubtable fueled by the musical references (“player piano”) in the description of the mechanism of action, leading to the (misguided) rejection of the importance of the principles. The earliest known implementation of the spread frequency concept was not until 1962, during the Cuban Missile Crisis using the work of the engineers at Sylvania Electronics initiated in 1957. The Sylvania Electronics engineers used TRANSISTOR to implement the concept at this point. At this time the patent has expired and Lamarr and Antheil did not receive credit for their contribution. Hedy Lamarr was

honored by the Institute of Electrical and Electronics Engineers: IEEE, for her contributions to modern telecommunications in 2002 (see **FREQUENCY HOPPING SPREAD SPECTRUM: FHSS**) (see [Figure L.6](#)).



(a)



(b)

Figure L.6 (a) Hedy Lamarr (1914–2000), born: Hedwig Eva Maria Kiesler. (Courtesy of Laszlo Willinger [1909–1989]; taken in 1943. Hedy Lamarr's name and likeness, used with permission from Denise Loder-DeLuca.) (b) Frequency-hopping, conceptual spectral outline.

Lamb, Horace, Sir (1849–1934)

[acoustics, geophysics, fluid dynamics, mechanics] Physicists and mathematician from Great Britain. Lamb's work influenced developments in ELASTICITY, SEISMOLOGY, TIDAL MOTION as well as ELECTRICITY AND MAGNETISM. The LAMB WAVE phenomenon is of primary interest to nondestructive testing (see [Figure L.7](#)).

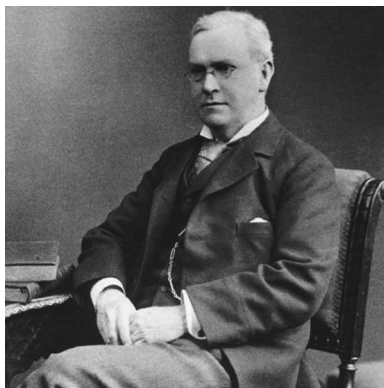


Figure L.7 Sir Horace Lamb (1849–1934).

Lamb, Willis Eugene (1913–2008)

[acoustics, atomic, computational, general, mechanics, nuclear, solid-state] Physicist from the United States. Lamb was known for his work on quantum-field theory. Lamb received the Nobel Prize in Physics in 1955 for the discovery of the quantum-mechanical shift in ENERGY levels associated with the HYDROGEN ATOM, the Lamb shift. Lamb received the Nobel Prize for his discovery of how the FINE STRUCTURE of hydrogen is revealing a discrepancy in the QUANTUM THEORY with respect to the electron and his concept of “virtual particles” that provide an energy shift named after him as the “LAMB SHIFT.” The concept of virtual particles can be interpreted as energy shift through the mass-energy equivalence concept. Lamb studied under JULIUS ROBERT OPPENHEIMER (1904–1967) and was a contemporary of ENRICO FERMI (1901–1954), ISIDOR ISAAC RABI (1898–1988), Edward Teller (1908–2003), and John Hasbrouck Van Vleck (1899–1980), with whom he interacted. While examining the fine-structure of transitions between $^2S_{1/2} \rightarrow ^2P_{1/2}$ and $^2S_{1/2} \rightarrow ^2P_{3/2}$ the high RESOLUTION of 10^{-4} GHz confirmed the Dirac predicted 2P fine structure (see [Figure L.8](#)).



Figure L.8 Willis Eugene Lamb (1913–2008). (Courtesy of Arizona Daily Star, Tucson, Arizona.)

Lamb shift

[atomic, general, nuclear, solid-state] Shift in hydrogen spectrum resulting from atomic interaction, specifically changes in ENERGY configuration resulting from positron–electron “pair” formation. This interaction can be induced by X-RAY irradiation of the MACROSCOPIC matter. This electromagnetic interaction generates an electric field that influences the photon–photon interaction, acting as a PHOTON scattering catalyst. The resulting shift in the excitation EMISSION SPECTRUM is referred to as Lamb shift. Spectral shift named after the discovery by Willis Lamb (1913–2008) during the LAMB–RETHERFORD EXPERIMENT as published in 1947. While examining the FINE STRUCTURE of transitions between $^2S_{1/2} \rightarrow ^2P_{1/2}$ and $^2S_{1/2} \rightarrow ^2P_{3/2}$ the high RESOLUTION of 10^{-4} GHz revealed that the $^2S_{1/2}$ and $^2P_{1/2}$ states with energy level at $n = 2$ are, contrary to prediction, not degenerate. It was however shown that the $^2S_{1/2}$ energy state was as a MATTER of fact shifted to a higher level by 1060 MHz, known as the Lamb shift. This shift can be attributed to radiative coupling between the electrons. This discovery formed a milestone in the development of QUANTUM electrodynamic theory (see Figure L.9).

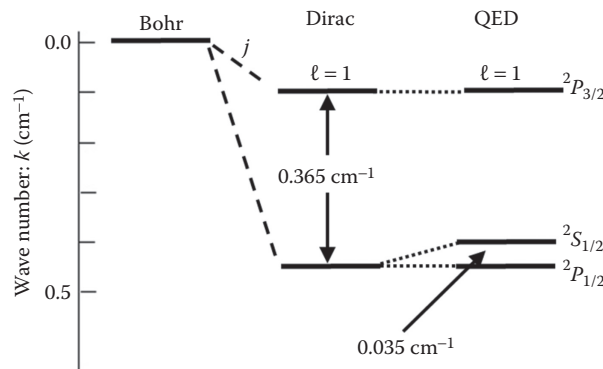


Figure L.9 Representation of Lamb shift. A refinement in the energy structure of the hydrogen $n = 2$ level in accordance with Bohr’s theory, Dirac theory, and quantum electrodynamics (QED) theory under the assumption of the Lamb shift. The Lamb shift removes the degeneration resulting from the quantum number j .

Lamb wave

[fluid dynamics, geophysics, mechanics] (Syn.: EVANESCENT WAVE) {use: pressure, imaging, ablation, weather, nondestructive testing}; a LONGITUDINAL WAVE comprised of RAREFACTION and compression traveling in a thin BOUNDARY LAYER of a plate. Described by SIR HORACE LAMB in 1916. Lamb wave require free boundary conditions (equivalent to an infinite wide space), with an infinite number of symmetric and antisymmetric modes. Displacement in the transverse direction within the medium are representative of the antisymmetric modes. Lamb wave can be initiated when the PHASE VELOCITY of a wave that is induced through external influences on a layer matches the phase velocity of a particular mode of Lamb wave. The phase velocity (v_p) of the incident longitudinal wave is derived from the group velocity (v_g) and the ANGLE of incidence (ϕ) with the layer as $v_p = v_g / \sin \phi$. The modes are described as a function of frequency and layer thickness and the derived DISPERSION curves. The modes are defined based on symmetric (S) or antisymmetric (A) format as S0; A0; S1; A1; ..., respectively. Lamb waves are used in nondestructive testing, identifying cracks in plates, such as the body of an airplane, and pipes. The illustration below shows the condensation pattern (strips of clouds) with an extremely regular interval parallel in one direction. The AIR above Hot Springs, Arizona, prior to this phenomenon showed a sharp horizontal demarcation several hundred meters up in the air, suggesting two air masses with different density parked on top of one another, with a front moving in from the East (sunset in the background). The moving front is squeezed in between two stagnant air masses, causing an elastic deformation RIPPLE to be generated; similar to pursuing one’s lips and blowing:

whistle (see Figure L.10). (Note that whistling generates a perfect sine wave in most cases, if not a superposition of only several sine waves; depending on any local variability in elastic nature of the SKIN.)

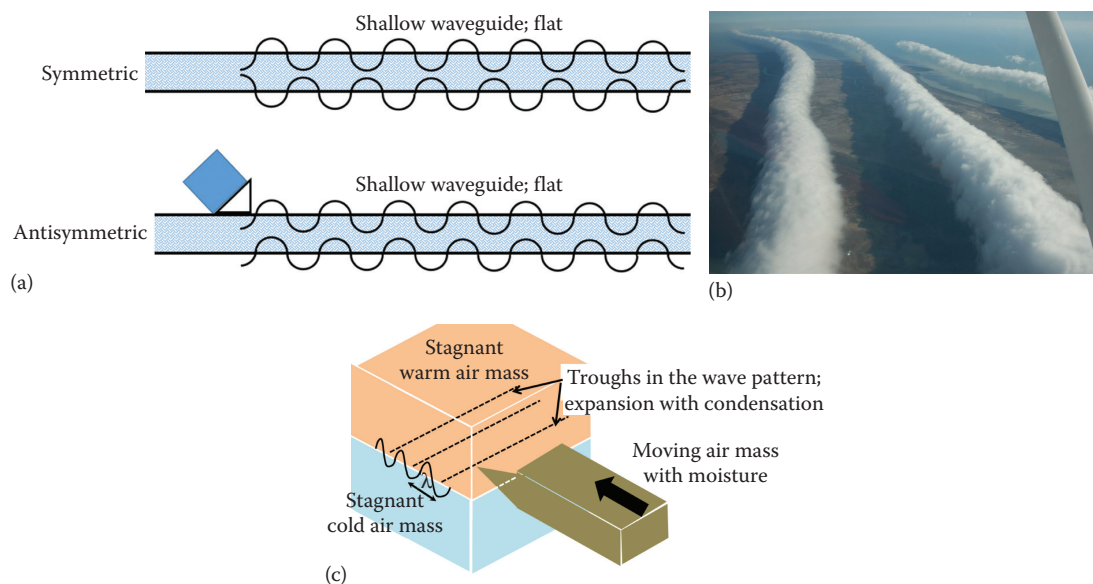


Figure L.10 (a) Lamb wave principle, (b) example of a Lamb wave in the atmosphere (Courtesy of Mick Petroff.), and (c) illustration of the process of the formation of a Lamb wave in the atmosphere.

Lamb–Retherford experiment

[atomic] Experimental configuration that lead to the verification of QUANTUM electrodynamic principles in 1947, as performed by WILLIS EUGENE LAMB (1913–2008) and his student Robert Retherford (1912–1981).

Lambda particle

[atomic, nuclear] BARYON particle as a subclassification of hadrons. Lambda particles have CHARM (c ; charm: c) of +1 (quark, spin: $(1/2)\hbar$, where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ Planck's constant; not ranking in "antiquark") or strangeness (s ; strangeness: s) of -1 (quark), associated flavors are "bottom" (b) and "top" (t). Furthermore, they are either neutral or have elementary charge +1. The nomenclature for the lambda baryons is as follows: Λ^0 ; quarks : uds, Λ_c^+ ; quarks : udc, Λ_b^0 ; quarks : udb, and Λ_t^+ ; quarks : udt. (Note: QUARK flavor—Up : u , Down : d , strange : s , Charmed : c , Bottom : b , and Top : t . The REST MASS of the lambda particle is 1115.60 MeV and has an average lifetime of $2.6 \times 10^{-10} \text{ s}$.)

Lambda point

[atomic, thermodynamics] Transition in SPECIFIC HEAT for helium, specifically the morphing between the states of helium-1 and helium-2. The plot of the specific heat of helium as a function of temperature resembles the shape of the Greek letter lambda: λ (see Figure L.11).

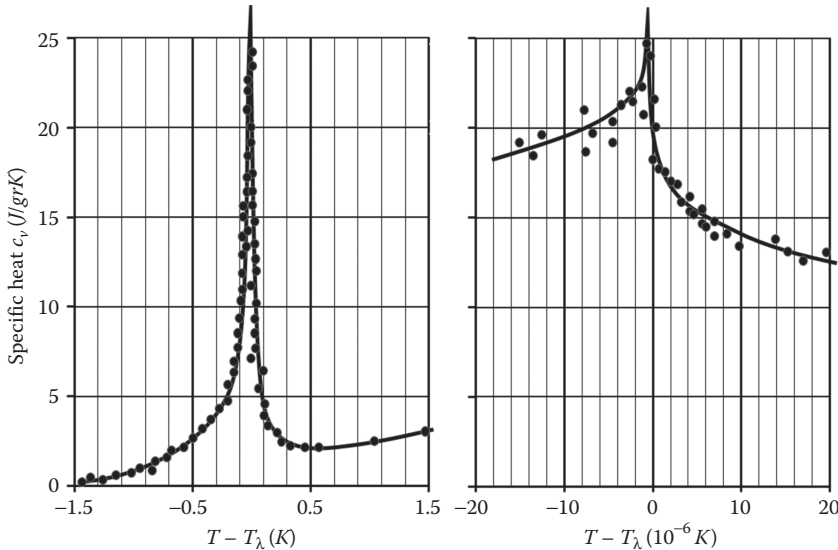


Figure L.11 Lambda point for helium.

Lambert, Johann Heinrich (1728–1777)

[general, thermodynamics] Physicist and mathematician from Switzerland. Lambert's experimental observations using the gas-based thermometer (THERMOSCOPE) as designed by GALILEO GALILEI (1564–1642), indicated the theoretical prediction of an ABSOLUTE ZERO temperature limit in 1770s. Lambert introduced hyperbolic function in trigonometry. Additional work by Johann Lambert is in the formulation of the diffuse emission from a surface (e.g., PHOSPHORESCENCE), known as LAMBERTIAN EMISSION PROFILE. Lambert also formulated the area calculations for hyperbolic triangles (with curved side), which do not have the ANGLES add to π . Additional work on attenuation of light with respect to penetration depth (z) in an attenuation, both SCATTERING and absorbing, medium decays exponentially with DISTANCE: $\Psi(z) = \Psi_0 e^{-\mu_{\text{att}} z}$, with Ψ the radiance magnitude of ELECTROMAGNETIC RADIATION (Ψ_0 incident on the surface), and μ_{att} the attenuation coefficient, the combined effect of loss of light from the original path resulting from absorption (extinction) and scattering. The attenuation equation is also known as the Beer–Lambert law. This attenuation is essential in X-RAY diagnostics. The influence of scattering on the attenuation as captured by his introduction of the concept of albedo (α_a), the ratio of the SCATTERING to the combined effect of scattering

and absorption. Generally, the albedo is used as an indication of reflectiveness (i.e., BACKSCATTER), where an albedo close to 1 represent total (diffuse) reflectivity (e.g., snow has an albedo of $\alpha_d = 0.9$) (see [Figure L.12](#)).



Figure L.12 Johann Heinrich Lambert (1728–1777).

Lambertian emission profile

[general, optics] Surface emission of light is proportional in MAGNITUDE to the cosine of the ANGLE with the normal to the surface: $\Psi \sim \Psi_0 \cos \theta$, in two-dimensional space (see [Figure L.13](#)).

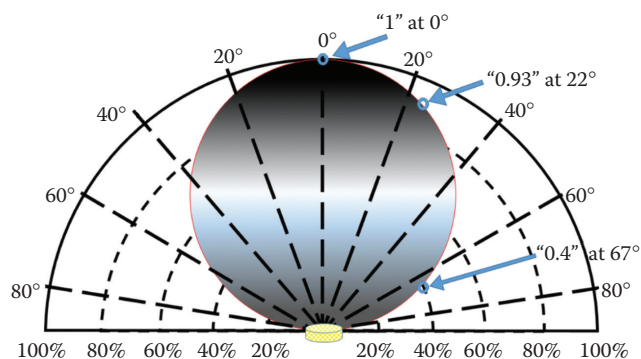


Figure L.13 Graphical representation of the Lambertian emission profile.

Lamé, Gabriel Léon (1795–1870)

[computational, mechanics] French mathematician and physicist who published his approach on stress and strain in cylinders in 1833 (see [Figure L.14](#)).



Figure L.14 Gabriel Léon Lamé (1795–1870).

Lamé coefficient

[acoustics, mechanics] In deformation the ELASTICITY of a medium can be defined with the Young's modulus (E_Y) and the POISSON'S RATIO (ν_p). These elastic properties are directly related to the stress $\sigma_{ij} = \lim_{\Delta A_j \rightarrow 0} (F_i / \Delta A_j)$ for a FORCE (F) in the i direction on a surface with normal in the j direction and strain ($\epsilon_{ii} = \partial v_i / \partial x_i$) in three dimensions as follows: $E_Y = \text{tensile stress/lengthwise strain} = [\mu_L (2\mu_L + 3\lambda_L) / (\mu_L + \lambda_L)]$ and $\nu_p = \text{strain/lengthwise strain} = \text{lateral contraction/lengthwise strain} = \lambda_L / 2(\mu_L + \lambda_L)$, where μ_L and λ_L are the Lamé coefficients, introduced by GABRIEL LÉON LAMÉ (1795–1870). The Lamé coefficients follow from the matrix description of three-dimensional deformation which in turn provides the coefficients (TENSOR) C_{mn} which relate stress and strain through $\sigma_{ij} = \sum C_{ijkl} \epsilon_{kl}$, where C_{ijkl} are the elastic moduli, which translates

into 6 one-dimensional stress–strain relations as $\sigma_i = \sum C_{ij} \epsilon_j$. The Lamé coefficients are now defined by $C_{11} = C_{22} = C_{33} = 2\mu_L + \lambda_L$, $C_{12} = C_{23} = C_{13} = \lambda_L$, and $C_{44} = C_{55} = C_{66} = \mu_L$ (see Figure L.15).

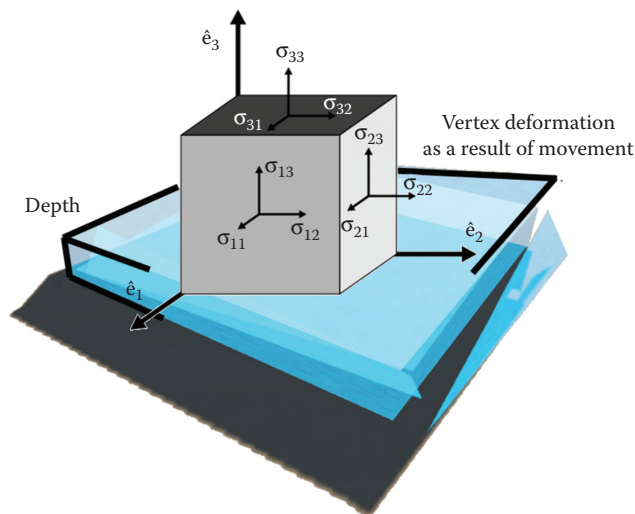


Figure L.15 Graphical illustration of elastic deformation, where $\hat{e}$ indicates the normal vector with respect to the three respective surface planes.

L

Lamé equations

[computational] When changing the coordinate system in Laplace equations to an ellipsoidal coordinate system, the Laplace equations convert to Lamé equations. The Lamé equations were developed by GABRIEL LÉON LAMÉ (1795–1870) in 1837 to solve for cylindrical stress. The ordinary differential equation is as follows: $d^2 y / dx^2 = (C_1 + C_2 \mathcal{P}(x)) y$, where C_1 and C_2 are constants, and $\mathcal{P}(x)$ is an elliptic function called the Weierstrass elliptic function. The most intriguing case is when $C_1 \sim n(n+1)$, $n = \text{integer}$. In the latter case the solutions include meromorphic functions, which extend into the complex plane. Generally, the solutions are ellipsoidal harmonic functions.

Lamina

[biomedical, fluid dynamics] Infinite wide plate, closed surface with density. In biology, this refers to a the structure and tissue composition of a layer in the WALL of a BLOOD vessel (see Figure L.16).

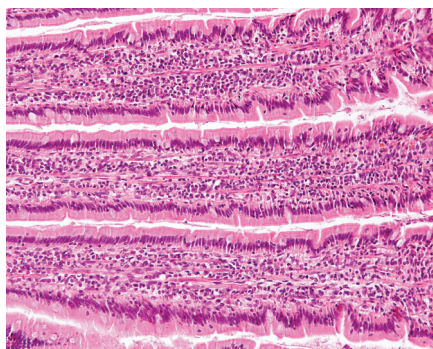


Figure L.16 Light microscope micrograph of the intestinal villi of the ileum portion of small intestine. Each villus contains a central axis of lamina propria covered with single columnar intestinal epithelium.

Laminar boundary layer, flat plate

[fluid dynamics] Flat surface that provides the idealized boundary conditions to maintain laminar flow.

Laminar flow

[biomedical, fluid dynamics, general] Parallel flow pattern devoid of **TURBULENCE**, very well organized with shear rate ($\dot{\gamma}$) that is linear with **SHEAR STRESS** (σ_s), as $\sigma_s = \eta(dv/dy) = \eta\dot{\gamma}$, with velocity v perpendicular to the shear direction, throughout the flowing medium (not accounting for **BOUNDARY LAYER** effects).

Laminar flow is considered to occur for **REYNOLDS NUMBER**: $Re < 2040$ (see [Figure L.17](#)).



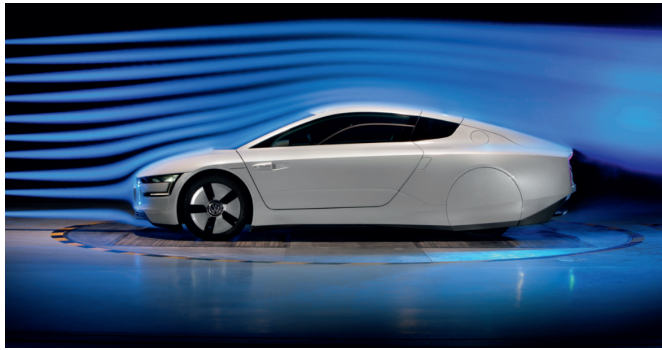
(a)



(b)



(c)



(d)

Figure L.17 (a) Example of engineering design for high-speed train to ensure laminar flow, (b) 1935 Rolls Royce PII Jonckheere Aerodynamic Coupe which presumably supports laminar flow, (c) aerodynamic bicycle helmet to ensure laminar flow around the head of the cyclist, reducing friction from an apparent vacuum that can appear behind the “irregular” shape of the human head resulting from turbulent flow, and (d) laminar stream lines around the Volkswagen XL1 hybrid automobile. (Courtesy Volkswagen Aktiengesellschaft.)

Laminar flow, pipes

[fluid dynamics] Linear flow in a round tube is symmetric around the central axis, creating a parabolic **FLOW** pattern with maximum velocity on the central axis. The velocity (v) is defined by the **DISTANCE** to the

WALL (r), the VISCOSITY of the LIQUID (η), the pressure gradient over the stretch of PIPE (P) with length L as well as the radius of the pipe (R): $v(r) = (P_2 - P_1)(R^2 - r^2)/4\eta L$ (see Figure L.18).

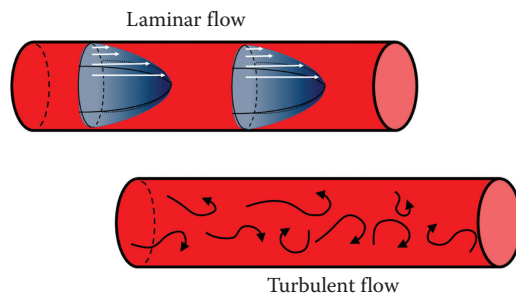


Figure L.18 Laminar pipe flow with velocity distribution. Turbulent flow transports fluids with a slower average velocity than under laminar flow conditions.

Laminar frictional resistance

[fluid dynamics] The effects of the restraining force between adjacent sliding layers (with effective area A), separated over a DISTANCE y , moving with velocity v defined as the VISCOSITY (η): $F = \eta A(v/y)$, also found in differential format (SIR ISAAC NEWTON [1642–1727]) in the format of shear: $\sigma = F/A$, expressed as $\sigma = \eta(dv/dy)$.

L

Laminar sublayer

[biomedical, fluid dynamics] Layer in mixed flow system where turbulent flow is separated from a different medium (e.g., WALL), with no-slip conditions, where the FLOW conditions are laminar. This is also referred to as the viscous sublayer. The REYNOLDS NUMBER decreases on approach to the boundary until laminar conditions are met (see Figure L.19).

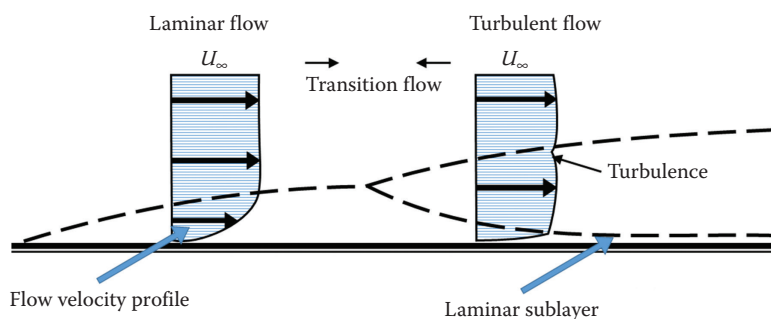


Figure L.19 Laminar sublayer, separating the turbulent layer from a surface over which the flow is guided.

Laminin

[biomedical, chemical] Protein chain in biological media, sometimes used to form peptides. Laminin is an essential component in certain CELL ADHESION processes, the chemical and electric gradient in the anchoring substrate will draw in cells for structural organization (see [Figure L.20](#)).

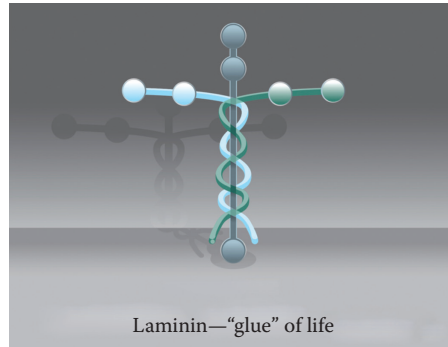


Figure L.20 Laminin protein analogy.

Land, Edwin Herbert (1909–1991)

[chemical, general] Scientist of the United States. Land is best known for his invention of the Polaroid CAMERA and film concept, next to the introduction of a dichroic POLARIZATION selective sheet. The POLYMER film is a NITROCELLULOSE (transparent) with iodoquinine sulfate crystals embedded. The iodoquinine sulfate (herapathite) oxidizes to form an instantaneous fixed IMAGE of the projected representation (see [Figure L.21](#)).



Figure L.21 Edwin Herbert Land (1909–1991). (Courtesy of Seymour “Sy” Brody, produced by Art Seiden.)

Landau, Lev Davidovich (1908–1968)

[astrophysics/astronomy, computational, energy, fluid dynamics, general, thermodynamics] Physicist from Soviet Russia (USSR) who contributed to the development of the general foundation of theoretical PHYSICS. His work covered the description of thermodynamic equations as well as the introduction of QUANTUM LIQUID also referred to as Fermi liquid, specifically of the “Bose”-type. Landau received the Nobel Prize in Physics in 1962 (see [Figure L.22](#)).



Figure L.22 Lev Davidovich Landau (1908–1968).

L

Landau theory

[computational, thermodynamics] Classical MECHANICS mechanism with respect to condensed MATTER, and in particular superfluidity. One specific area of interest is LIQUID helium. The theory of second-order phase transitions was introduced by LEV DAVIDOVICH LANDAU (1908–1968) in 1937. The concept relies on the fact that the minimum GIBBS FREE ENERGY (G) determines the state of the equilibrium situation for a PHASE of a medium at a CRITICAL TEMPERATURE T_c . The principle uses the fact that the first-order differential for the free energy is not zero: $\partial G / \partial T|_{T=T_c} \neq 0$, delivering a situation where the ENTHALPY (S) and ENTROPY (H) are also not zero; under the condition $G = G_0 + \Delta H - T\Delta S$, note ΔH is the LATENT HEAT. Additionally, the following conditions also follow: $\partial^2 G / \partial T^2|_{T=T_c} \neq 0$, and $\partial^3 G / \partial T^3|_{T=T_c} \neq 0$. Expressed in ELECTRON SPIN field distribution this translates the Gibbs free energy into $G = B\Phi_s + r\Phi_s^2 + s\Phi_s^4$, where Φ_s represents the SPIN field, also known as the “total magnetization,” $r = r_0(T - T_c)$, B the external MAGNETIC FIELD and $s = (1/N)\sum_i s_i$ the magnetization. Below the critical temperature the medium may reach superfluidic conditions, resembling the absence of VISCOSITY. In liquid helium this relates to the Bose–Einstein condensate.

Landau–Darrieus instability

[astrophysics/astronomy, computational, energy, fluid dynamics, thermodynamics] A hydrodynamic instability in a solar flare eruption formation. A thermonuclear flame can be described as being affected by gravitational and CAPILLARY forces. The DEFLAGRATION wave of a solar flare (i.e., ejected flame) can experience effects from the ash, which is light compared to the fuel and the vertical (i.e., radially outward) velocity of the ash (v_{ash}) is different from the vertical velocity of the fuel (v_{fuel}). The instability results in “creasing” of the flame. The WAVE DISPERSION associated with the wavenumber of the phenomenon (k) in the flare propagation is described by $\tau_{\text{decay}}^2 (v_{\text{fuel}} + v_{\text{ash}}) + 2\tau_{\text{decay}} k v_{\text{fuel}} v_{\text{ash}} + k^2 (v_{\text{fuel}} - v_{\text{ash}}) v_{\text{fuel}} v_{\text{ash}} - g k (v_{\text{fuel}} - v_{\text{ash}}) = 0$, where τ_{decay} represents the

DECAY rate of the combustion and g is the GRAVITATIONAL ACCELERATION on the STAR. The phenomenon is also influenced by Rayleigh–Taylor instabilities as well as Kelvin–Helmholtz instabilities. The dispersion creates TURBULENCE resulting from the convective instabilities next to the deflagration itself (see Figure L.23).

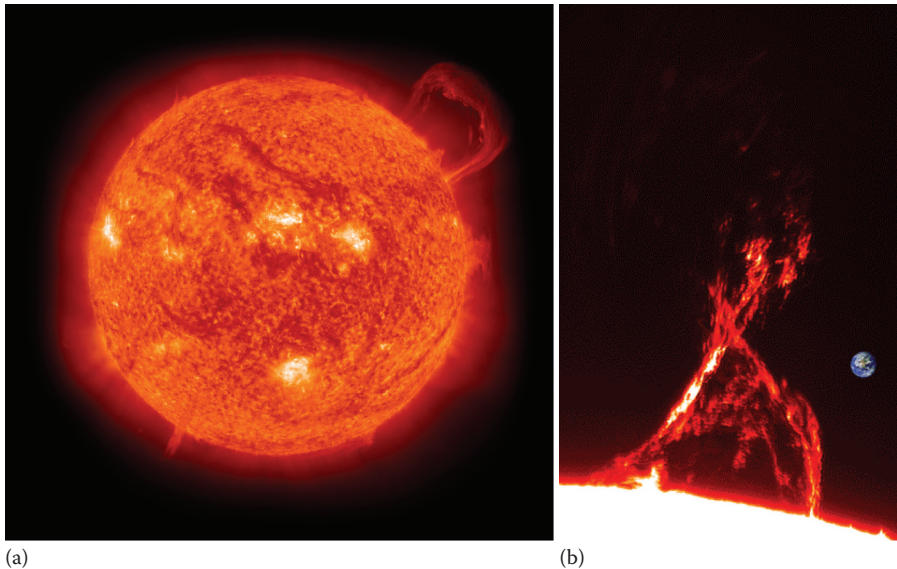


Figure L.23 (a,b) Landau–Darrieus instability of a solar flare. (Courtesy of National Aeronautics and Space Administration [NASA], Washington, DC.)

Lande's g -factor

[atomic] See **G-FACTOR**, TOTAL ANGULAR MOMENTUM.

Lane–Emden equation

[astrophysics/astronomy, thermodynamics] Poisson equation expressed in dimensionless format. The Lane–Emden equation defines the gravitational potential in a Newtonian environment pertaining to the hydrostatic equilibrium describing the plasma PRESSURE (P) (as a GAS) of stars: $P = \kappa \rho^{\gamma_t}$, where κ and $\gamma_t = (n_p + 1)/n_p$, with n_p the polytropic index, are process constants and ρ the density.

Langevin, Paul (1872–1946)

[acoustics, computational, electromagnetism, imaging, solid-state] Scientist and engineer from France. Langevin worked on PARAMAGNETISM and also introduced the first underwater sonographic probing system. The first operation mechanism of SONOGRAPHY used a QUARTZ transducer operating under the PIEZOELECTRIC EFFECT. The sonograph was used in submarines for range detection and navigation, PAUL LANGEVIN is sometimes referred to as the father of ULTRASONICS. Other contributions of Paul Langevin are in computational PHYSICS with respect to his description of dynamic properties, specifically

under paramagnetic conditions captured by the LANGEVIN FORMULA as well as the LANGEVIN EQUATION for PARTICLE displacement in a viscous liquid (see Figure L.24).



Figure L.24 Paul Langevin (1872–1946).

Langevin equation

[acoustics, computational, electromagnetism, imaging, solid-state] The equivalence of BROWNIAN MOTION for a PARTICLE with mass m suspended in a LIQUID can be described by an equation of MOTION defined as $m(dv/dt) + \gamma_{\text{damp}}v = \sum F(t)$, where v is the velocity of the particle in random motion as a function of time (t), with a dampening force: $\gamma_{\text{damp}}v$ to equal the sum of the external forces changing with time (F). The external forces may be applied based on compression, as under ULTRASOUND wave propagation. The solutions to this Langevin equation provide the coefficients (a and b) to the Fokker–Planck equation: $\partial P/\partial t = (1/2)(\partial^2/\partial x^2)(bP) - (\partial/\partial x)(aP)$, where P represents the local pressure and making the following substitutions: $a = \alpha v$, $\alpha = \gamma_{\text{damp}}/m$, and $b = 2D$, where $\gamma_{\text{damp}} = (1/k_b T) \int_0^\infty F(t)F(0)dt$ is the dampening coefficient derived from STOKES' LAW, where Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$. This transforms into an expression for Brownian motion, known as the Ornstein–Uhlenbeck equation: $\partial P/\partial t = D(\partial^2/\partial v^2)P + \alpha(\partial/\partial v)(vP)$.

Langevin formula

[acoustics, computational, electromagnetism, imaging, solid-state] When the MAGNETIC SUSCEPTIBILITY (χ_{mag}) of a material is positive the material is considered to be paramagnetic. The magnetic susceptibility is the Langevin expression for the balance between thermal disorder (as a function of MOTION due to temperature T) and the preferential alignment of the magnetic dipoles, with magnetic moment μ_{mag} , with respect to an externally applied MAGNETIC FIELD (B) as: $\chi_{\text{mag}} = \mu_0 N \mu_{\text{mag}}^2 / 3 \text{ kT}$, where $\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$ is the DIELECTRIC permeability of VACUUM, N the number of magnetic dipoles per unit volume, and $k = 1.380658 \times 10^{-23} \text{ J/K}$ the Boltzmann constant. Also referred to as the MAGNETIC SUSCEPTIBILITY.

Langmuir, Irving (1881–1957)

[atomic, chemical, solid-state] Scientist and chemist from the United States. Langmuir contributed to the theoretical description of the atomic structure and is attributed with the invention of the incandescent light bulb. Langmuir received the Nobel Prize in Chemistry in 1932 (see Figure L.25).



Figure L.25 Irving Langmuir (1881–1957).

Langmuir equation

[biomedical, computational, nuclear] Exposure of a surface to the molecules of a SOLUTE or GAS during random MOTION. The surface will adsorb the molecules depending on concentration or pressure respectively (P) within a fractional of the total MAGNITUDE of the medium (θ_L). In order of magnitude, this is expressed as $\theta_L = \alpha_L P / (1 + \alpha_L P)$, where α_L is the Langmuir ADSORPTION coefficient which is a function of temperature and adsorption BINDING ENERGY. Also known as the Langmuir isotherm.

Langmuir probe

[atomic, nuclear] Devise inspired by IRVING LANGMUIR (1881–1957) to determine the electron density, electron temperature, and electric potential of a plasma. The mechanism of action is indirect, relying on the addition of one single or more (quantity known) electrons to a system and determining the changes to the PLASMA configuration, specifically under time-varying conditions. The theoretical description is based the characteristic current–voltage of the Debye sheath. The Debye sheath represents a layer in a plasma with excess POSITIVE CHARGE resulting from a greater density of POSITIVE IONS.

Laplace, Pierre-Simon de, Marquis de Laplace (1749–1827)

[astrophysics/astronomy, computational, general] Mathematician, physicist, and astronomer from France. Laplace is best known for his work in PROBABILITY as well as equation of MOTION. His theoretical work on the PLANETARY MOTION as well as the description of orbits and shapes of planets contributed to the first known attempt to describe the formation and stability of the SOLAR SYSTEM. Other work by Laplace

involves the theoretical formulation of various thermodynamic and FLUID dynamic concepts. The LAPLACE EQUATION carries his name (see [Figure L.26](#)).



Figure L.26 Pierre-Simon Laplace, Marquis de Laplace (1749–1827). (Courtesy of Grands hommes et grands faits de la Révolution française (1789–1804); Jouvett & Cie, éditeurs; Magasin Pittoresque (E. Best), Paris, France, 1889.)

L

Laplace equation

[atomic, biomedical, computational, fluid dynamics] Second-order homogeneous differential equation: $\nabla^2 X = \text{div grad } X = 0$, for a general function X describing, for instance, MOTION of heat and ∇^2 the Laplacian operator; a second-order derivative in the coordinate system of preference (e.g., Cartesian, cylindrical, or spherical), introduced by PIERRE SIMON DE LAPLACE, MARQUIS DE LAPLACE (1749–1827).

Laplace law

[biomedical, fluid dynamics, mechanics] {use: lung, pressure, communicating vessels} A vessel under pressure will generally strive for equal distribution of forces, resulting in a spherical geometry. This assumption is based on constant and equal material properties. One example that does not fit the spherical profile is an inflated rubber balloon. A vessel with radius r has the following relationship between the pressure inside the vessel P and the tension T in the WALL: $P = 2T/r$. The condition described by the Laplace law is a result of the force equation describing equilibrium between the force applied by pressure on to half domes and the tension along the circumference of the sphere. Considering a sphere with radius r and pressure P the force on one hemisphere is $F_{\text{pressure}} = \pi r^2 P$, the force exerted by tension is $F_{\text{tension}} = 2\pi r T$. Equating the two forces yields the Laplace condition. In this situation when two vessel of unequal pressure are connected, the higher pressure will induce FLOW due to the PRESSURE GRADIENT and if the generally smaller bulb were flexible it would disappear, otherwise it would merely empty out to the point of equal pressure. In a biological system such as the lung, the situation of unequal pressure between adjacent alveoli is very likely. The alveoli compensate for this by applying a variable tension through a connective matrix of ELASTIN, collagen fiber and the septa, resulting in an omnidirectional tension that is volume/size dependent. Additional traction influences may be provided by means of a coating on the inner surface with a SURFACTANT that diminishes the SURFACE TENSION as the circumference of the bulb decreases. The alveolar

structure thus prevents the lungs from gradually turning into one large bulb which significantly reduces surface area, whereas the surface area provides the opportunity for the exchange of oxygen and carbon dioxide and area MAGNITUDE is crucial to the efficiency of the GAS EXCHANGE. The concept was introduced by PIERRE SIMON DE LAPLACE, MARQUIS DE LAPLACE (1749–1827) (*also see HOOKE'S LAW*) (see [Figure L.27](#)).

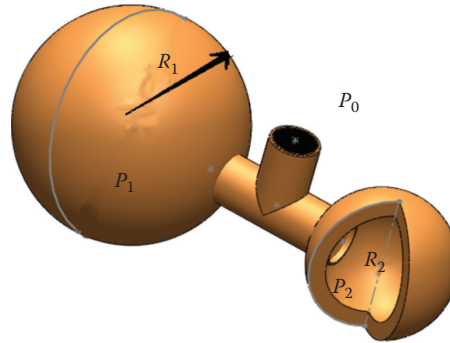


Figure L.27 Illustration of the concept of the Laplace law.

Laplace transform

[computational] The cause–effect description between a perturbation $P_{\text{cause}}(t)$ with response $R_{\text{effect}}(t)$ as a function of time in a linear system can be expressed as $R_{\text{effect}}(t) = \int_{-\infty}^t \chi(t-t') P_{\text{cause}}(t') dt'$, where χ describes the response function over time prior to time t , based on the work of PIERRE SIMON DE LAPLACE, MARQUIS DE LAPLACE (1749–1827). The other side of the coin is the fact that this defines the convolution: $R_{\text{effect}}(t) = (\chi * P_{\text{cause}})(t)$. The convolution yields the FOURIER TRANSFORM: $R_{\text{effect}}(\omega) = \int_{-\infty}^{\infty} R_{\text{effect}}(t) e^{-i\omega t} dt = \int_{-\infty}^{\infty} (\chi * P_{\text{cause}})(t) e^{-i\omega t} dt = \chi(\omega) P_{\text{cause}}(\omega)$. The response as a function of time $R_{\text{effect}}(t)$ can be measured to yield the frequency-dependent response function $\chi(\omega)$, where $\omega = v2\pi$, the ANGULAR FREQUENCY and v the frequency of the event.

Laporte, Otto (1902–1971)

[atomic, computational, nuclear, quantum, solid-state] Physicist from Germany who made significant contributions to the theoretical formulations of quantum PHYSICS concepts, fluid mechanics, WAVE mechanics, and OPTICS (see [Figure L.28](#)).



Figure L.28 Otto Laporte (1902–1971).

Laporte rule

[atomic, nuclear, optics, quantum, solid-state] Definition in optical SPECTROSCOPY with respect to atoms, and molecules that are symmetric around an INVERSION center (centrosymmetric), relating the forbidden electron transitions. Named after the work by OTTO LAPORTE (1902–1971). The transitions that only would involve a redistribution of the electrons within a specific SUBSHELL will be forbidden based on ENERGY balance, hence these will not produce emission. In case the symmetry is disrupted, these transitions will now be allowed due to the change in energy. In case these apparently FORBIDDEN TRANSITIONS are observed the local (MOLECULE/ATOM) energy configuration must be disturbed, that is, the structure is no longer centrosymmetric, which may occur in oscillatory form. The periodic disturbance will be experimentally recognized in a periodic spectral emission format.

Large Eddy simulation (LES)

[biomedical, computational, fluid dynamics] Mathematical model used in computational FLUID DYNAMICS, specifically pertaining to TURBULENCE. Fully developed turbulence is achieved under high REYNOLDS NUMBER: $Re \gg 10^3$. The turbulence is captured by a VORTEX stretching term $\vec{\omega} \cdot \nabla \vec{v}$, where $\vec{v}$ is the FLOW velocity vector and $\vec{\omega} = \omega_0 e^{i\gamma t} e_i$ the “VORTICITY” (equivalent rotational MOTION, with representative angular velocity), where e_i the i th unit vector for dimension in a n -dimensional system ($i < n$), $\omega_0 = \omega(t)|_{t=0}$ and γ_v the EIGENVALUE of the matrix solution ($\mathcal{D}$) to the adjusted Euler/Navier–Stokes approach: $\mathcal{D}\omega/\mathcal{D}t = \mathcal{D}\omega + \nu\Delta\omega$. This is different than the analytical approach by means of Navier–Stokes equation SOLUTION, even with turbulence incorporated. This is usually solved through finite-element methods. One example of a condition that would illustrate these conditions is the flow from the HEART as the VALVE opens into the AORTA (see Figure L.29).

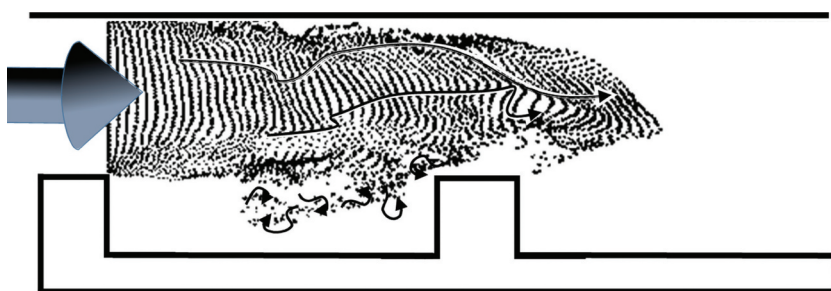


Figure L.29 Graphical representation of a large eddy simulation for turbulent flow over a ridge for Reynolds number $Re = 1.10 \times 10^4$ where the partially dotted lines are isovelocity lines.

Larmor, Joseph, Sir (1857–1942)

[atomic, general, nuclear, thermodynamics] Mathematician and physicist from Great Britain. The work of Sir Larmor dates back to 1901, when he described the particles emitted by CATHODE under high electrical potential as electrons, negatively charged which help a positively charged core. The model does not describe the ATOM with electrons around a NUCLEUS as of yet. Other works of Larmor is in the mathematical description of the axial spinning of the MAGNETIC moment of a charge in which the axis of the magnetic moment has a center point in common with the axis of revolution but where the magnetic moment vector does not line up with the axis of rotation. The vector moves in precession around the axis at a fixed ANGLE under constant ENERGY, that is, LARMOR PRECESSION. The Larmor precession directly relates to magnetic RESONANCE imaging. The PRECESSION occurs with a regularity that is defined by the LARMOR FREQUENCY (see Figure L.30).



Figure L.30 Sir Joseph Larmor (1857–1942).

Larmor frequency (ω)

[atomic, biomedical, nuclear, quantum] Frequency at which the MAGNETIC VECTOR of the ELECTRON SPIN pivots in angular MOTION around the axis of rotation under the influence of an applied external MAGNETIC FIELD (B): $\omega = \gamma B = eH/2mc$, where γ is the GYROMAGNETIC RATIO, e/c the electron charge in electromagnetic units, e electron charge in Coulomb, $c = 2.99792458 \times 10^8$ m/s the speed of light, and $H = B/\mu_0$, where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A $= 4\pi \times 10^{-7}$ H/m $= 4\pi \times 10^{-7}$ N/A² is the magnetic permeability for vacuum $\omega_0 = \gamma B_0$. The concept was introduced in 1897 by SIR JOSEPH LARMOR (1857–1942). The Bloch equation describes the magnetization vector behavior as it applies to nuclear magnetic RADIATION found in magnetic RESONANCE imaging as $dM/dt = M \times \gamma B$, where M = magnetization vector and t = time. The operator $\times$ represents vector multiplication.

Larmor precession

[atomic, biomedical, nuclear, quantum] Precession of a (revolving) charged PARTICLE when subjected to an external MAGNETIC FIELD. The PRECESSION will take place with the LARMOR FREQUENCY (see Figure L.31).

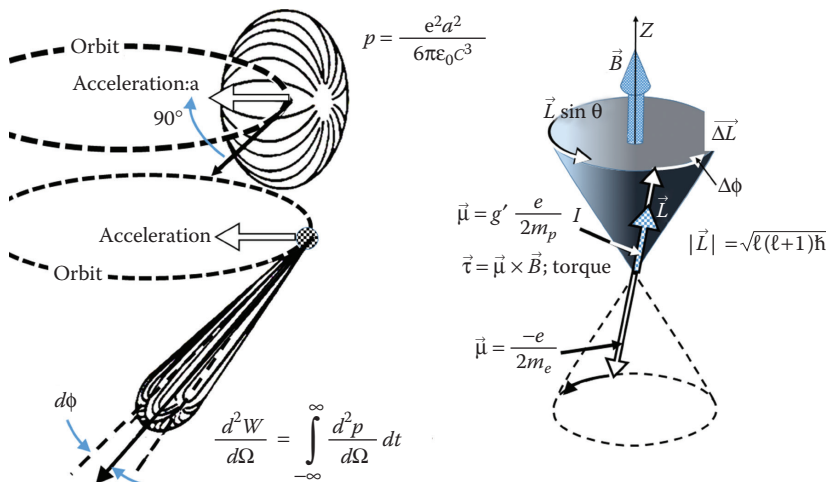


Figure L.31 Graphical representation of the Larmor precession and frequency concept.

LASER

[biomedical, chemical, optics, thermodynamics] Acronym for *Light Amplification by Stimulated Emission of Radiation*. Coherent source of directional ELECTROMAGNETIC RADIATION of a single wavelength of a narrow spectral emission bandwidth. The word LASER is documented in the lab notebook of one of the claimed inventors, GORDON GOULD (1920–2005) from the United States, dated November 13, 1957; against the patent claims of constructing the first operational laser by THEODORE HAROLD MAIMAN (1927–2007). Both scientists were inspired by the theoretical work of CHARLES HARD TOWNES (1915–2015) and ARTHUR LEONARD SCHAWLOW (1921–1999) in 1958. The primary concept of “STIMULATED EMISSION” was introduced by ALBERT EINSTEIN (1879–1955) in 1917. The controversial but final decree on the first person to construct a working laser has been granted to Theodore Maiman. Theodore Maiman introduced his ruby laser (Cr_2O_3) in 1960, emitting in the (infra-) red (694.3 nm). Stimulated emission is the emission of an identical photon to the PHOTON “passing” the atomic system that has an electron in an excited state with equal or greater ENERGY than the energy of the incident photon. The physical DECAY in energy state produces an accelerated electron, which is the primary requirement for the generation of electromagnetic waves. The electron MOTION by itself produces a current which induces a magnetic field; AMPÈRE’S LAW. An accelerated electron will have a changing electric field (GAUSS’S LAW), resulting inherently in the generation of a changing MAGNETIC FIELD, hence electromagnetic radiation is the ultimate result. All these concepts are captured by the electromagnetic theories of JAMES CLERK MAXWELL (1831–1879). Laser light is coherent, representing the fact that the PHASE of all the photons are aligned, in-phase. Incoherent sources, such as a light bulb, produce light from multiple oscillating charges that are not synchronized, nor do they have any constraints on the emission wavelength. Any LIGHT SOURCE requires a medium, for lasers the restriction on the formulation of the medium are very strict to ensure the generation of either a single wavelength or a narrow EMISSION SPECTRUM that can be confined by optical means to provide laser emission at a single wavelength only. The atoms and molecules in a medium used for stimulated emission interact with electromagnetic radiation in three manners: absorption, spontaneous emission, and stimulated emission. The absorption of photons results in an excited state. EXCITED STATES may also be induced by means of other energy sources, such as electrical current (e.g., gas laser and DIODE LASER) or chemical reactions (chemical laser). The spontaneous emission where the excited electron decays to the GROUND STATE may be the initial photon release, which is subsequently used to excite the decay of an entire population of excited electrons by stimulated emission. The laser mechanism of action relies on the continuous generation of a large quantity of excited electronic states for the atoms and molecules in the medium to provide the “fuel” for the operation of stimulated emission. The release of a single wavelength photon stream constitutes MONOCHROMATIC LIGHT. Furthermore, the optical construction of the excitation mechanism and emission medium results in a parallel beam. The beam is by definition coherent since all photons are traveling in sync and are released though excitation from the initial photon with cascade effect: 1, 2, 4, 8, 16, ... photons. The optical construction of the laser is called a cavity, confining the photons in a linear path between two mirrors: the total reflection mirror and the output MIRROR with reflectivity slightly less than 100%. In addition to the fact that the excited electron states need to be replenished to maintain the conditions for stimulated emission, the excited states need to have a surplus. The excited states also need to remain stable long enough to allow for stimulated emission to occur, not decay spontaneously. The third requirement is that the photons will need to be confined to the medium in persistent excited states long enough to provide stimulated emission. The excitation mechanism will greatly depend on the type of laser. The long-lived excited state is referred to as a metastable state, with lifetime exceeding 10^{-8} s, to ensure the preferential occurrence of stimulated over spontaneous emission. The metastable excited state condition is the result of the chemical design of the medium; the type of laser. The final requirement is satisfied through a geometric and optical design that confines the photons to a linear path by means of accurate placement of mirrors on opposite sides of the medium with associated optical constraints. One mirror having 100% reflectivity and one mirror with less than 100% reflectivity; reflectivity requirements depend on the application, operation (continuous or pulsed), and the excitation mechanism (chemical constituents of the medium and the excitation energy delivery). The principle of ensuring an excess of stimulated electron energy states for the medium is known as “Einstein population inversion.” The Einstein population

inversion is based on the work of ALBERT EINSTEIN (1879–1955). The Einstein population inversion will require an amount of energy that is a function of the total number of electron targets for excitation and the excitation efficiency with respect to the interaction between the excitation energy source and the atomic configurations in the “laser medium.” The excitation efficiency also will depend on the number and energy configuration of the available excitable states. The excited state may have several bands, which can be split into various modes. Each energy mode will be defined through a characteristic lifetime (τ_e). In the Einstein population inversion scheme, the number of modes ($\square_m$) at a single energy level are defined by the denomination N_m . Assuming for convenience a system with only two modes (N_1 and N_2), the MINIMUM ENERGY requirements for sustained stimulated emission can be derived. In case externally delivered light is used to induce excited states, the excitation photon energy is defined through the Planck relationship: $E = h\nu = b(c/\lambda)$ ($b = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck’s constant, ν the electromagnetic frequency, λ the associated wavelength, and $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of light). In order for excitation to be effective, the incident photon energy needs to match the difference in energy level between the ground state (E_1) and the excited state (E_2) in the two-state system: $E_2 - E_1 = h\nu_0$; ν_0 the emission wavelength. The required number of excited states (N_m) to provide a self-sustained operation yield the required pump power: $P = N_m h c / \lambda_0 \tau_e$. The POPULATION INVERSION is dominated by the ratio between the characteristic lifetime and the emission lifetime (τ_e). This provides the population difference between the two hypothetical states as the “POPULATION INVERSION”: $\Delta N = N_2 - N_1 = N_m \tau_e / \tau_e$. Keeping in mind the initial condition of spontaneous emission, the decay rate for the excited electrons is directly proportional to the number of excited states $dN_2/dt = -A_{21}N_2 = -R_{21}N_2 = -B_{21}U(\nu_0)N_2$, with A_{21} the PROBABILITY coefficient for spontaneous emission, also referred to as Einstein coefficient; B_{21} the stimulation probability; and $U(\nu_0)$ the energy distribution derived from the Planck equation $U(\nu_0)d\nu = \nu^2/c^3 h \nu \{ \exp(h\nu/k_b T) - 1 \}^{-1} d\nu = E' h \nu n d\nu$ ($k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann coefficient, T the ABSOLUTE TEMPERATURE, n the average number of resonant energy density states, and E' representing the resonant energy density per photon/excited electron), respectively, under equilibrium boundary conditions: $U(\nu_0) = A_{21} \{ B_{12} [N_1/N_2] - B_{21} \}$. The factor $R_{21} = \Phi_{\text{phot}} \sigma_{21}$ represents the stimulated emission rate, as function of the photon flux (Φ_{phot}) and (σ_{21}) the CROSS SECTION for stimulated emission under influence of an incident photon. The photon absorption providing the stimulated states follows the same principle: $dN_1/dt = R_{12}N_1 = -B_{12}U(\nu_0)N_1$, where B_{12} the absorption coefficient. The coefficients A_{21} , B_{21} , and B_{12} are the Einstein coefficients. Under 100% efficiency the metastable state is defined with the decay rate provided as $dN_2/dt = -A_{21}N_2 + B_{12}U(\nu_0)N_1 - B_{21}U(\nu_0)N_2 = -dN_1/dt$. The metastable state is further defined through $B_{12} = (g'_1/g'_2)B_{21}$, where the RADIATION weights g'_1 and g'_2 for the energy levels are correlated through $N_2/N_1 = (g'_1/g'_2) \exp(-h\nu/k_b T)$. The transitions are confined under the PAULI EXCLUSION PRINCIPLE and the de Broglie orbital restriction. These conditions describe the situation of one-to-one relationship between the stimulated and spontaneous emission under the condition $n < 1$, while $n > 1$ will produce stimulated emission. The fact that the electron orbit is not perfect enhances the broadening of the energy spread line. The final emission linewidth will follow from the ultimate optical configuration of the cavity. Once stimulated emission has been accomplished (by setting the appropriate operational conditions), the photons need to be harnessed for amplification. Placing mirror on opposite side provides a means for amplification in the direction of propagation $\hat{z}$: $d\Phi_{\text{phot}}/d\hat{z} = d\Phi_{\text{phot}}/cdt = dN/dt = R_{21}N_2 - R_{12}N_1 = \Phi_{\text{phot}}\sigma_{21}N_2 - \Phi_{\text{phot}}\sigma_{12}N_1 = \sigma\Phi_{\text{phot}}\Delta N$, assuming that the cross sections are equal. The critical population inversion based on a cavity with a medium of length ℓ , and mirrors with reflectivity r_1 and r_2 and stimulated condition information, comes to $\Delta N_c = -\ln(r_1 r_2) / 2\sigma\ell$. The excitation source is required to have a greater energy content than the emitted photons, hence the pump source has either a shorter wavelength of the energy from the electrical current of chemical reaction is substantial within the time frame of the stable excited electron. The PUMP efficiency for laser is only a few percent and the remaining energy will need to be discarded as heat, requiring a cooling mechanism. Lasers are classified based on the medium and the following categories are recognized: chemical, diode, dye, gas, SOLID-STATE, and free-electron laser (FEL). Chemical laser operate based on energy released from either a chemical FLOW of medium with irreversible reaction achieved at MIXING or a reversible chemical reaction. Chemical lasers typically use molecular rather than atomic transitions. One chemical laser, atomic iodine, does operate on atomic level (emission at $1.3\mu\text{m}$), while hydrogen fluoride (HF) and deuterium fluoride

(DF) provide examples of laser operating on molecular level. Due to the low energy content of the chemical reaction, the emission wavelength will be in the INFRARED. The HF laser has broad emission spectrum due to the ill-defined energy content of the molecular chemical reaction, operating in the band 2.6–3.3 μm , as do virtually all chemical lasers. The diode laser or semiconductor laser uses the standard semiconductor materials used in diodes and induces light emission at the *pn*-JUNCTION resulting from electrical current, encapsulated by mirrors. The accelerated charge principle is achieved by means of the applied electrical potential and obligatory current, forcefully dislocating electrons and inherent charge recombination with holes. Continuously creating new holes by migrating electrons provides the photon emission. An aluminum–gallium–arsenide (AlGaAs) semiconductor laser, for instance, produces light in a broadband ranging from 760–790 nm, and a gallium–arsenide (GaAs) semiconductor laser, for instance, produces light in a broadband ranging from 807–840 nm. Generally, diode laser are producing low power output, but this is still a developing field. Dye lasers operate on the flow of a CHROMOPHORE in LIQUID form that is excited by an external laser or a flash lamp. Due to the relatively broad emission spectrum, resulting from the broad excitation energy range, dye lasers are commonly tunable, and can be adjusted to the specific needs of the application. One favorite pigment for dye laser operation is the rhodamine chromophore. Dye lasers are popular in tattoo removal just because of the ability to tune the laser for optimal parameters with regard to the tattoo dye, the skin COLOR, and the vascularization in the treatment area. Some dye lasers can be tuned in the spectrum ranging from 360–720 nm, with continuous improvements and expansions as technology progresses. Liquid laser may be considered dye lasers, and groups have achieved laser action from their favorite alcoholic substance; for instance, the whiskey laser. Gas lasers use an electrical discharge as the pump mechanism in various noble gases, ranging from argon, to helium–neon and krypton ION. One gas laser operating at a very short wavelength is the Excimer laser (xenon chloride) operating at 308 nm nitrogen laser at 337.1 nm. Due to the temporary nature of the gas discharge these are primarily pulsed lasers. The solid-state laser is where it all started with the ruby crystal. Solid-state lasers generally rely on pumping by means of light sources: other lasers or flash lamp. The ruby laser uses a “dope” to provide the narrow emission excitation process, in this case chromium imbedded in a sapphire LATTICE, emitting at 694.3 nm. Another well-known solid-state laser is the neodymium:yttrium–aluminum–garnet laser, where the neodymium dope provides the wavelength of choice either at the first wavelength of 1064 nm, or the second transition at 1334 nm. A different class of laser is the FEL, which relies on the perturbation of an electron beam to generate light emission, initially emitted as a CATHODE ray. The cathode can be, for instance, a crystal structure of lanthanum hexaboride (LaB_6). The perturbation is referred to as “wobble,” which is provided by an alternating magnetic field B_w . FEL instruments are rather large and are several hundred cubic meters in size. The electrons are traveling at relativistic velocities and produce emissions (λ_L) proportional to the wobble FREQUENCY (ν_w , respectively wavelength λ_w): $\lambda_L = (\lambda_w/2\gamma_r) \{1/[1 + (eB_w\lambda_w/2\pi m_e c^2)]\}$, based on the electron REST MASS m_e and the relativistic correction factor $\gamma_r = (1 - \beta_r^2)^{-1/2}$, with β_r the relativistic ratio of the electron velocity (v_r) to the speed of light (c): $\beta_r = v_r/c$. Lasers can operate in various modalities: continuous wave (CW), pulsed (on/off), and superpulsed. Examples of superpulse are Q-switched and mode-locked delivery. Lasers are classified based on their wavelength, exposure duration, and power output. The classification is influenced by the accessible emission limit (a laser property) describing the maximum level of laser radiation that the device can generate: luminescent exposure and power (Watt). The classification is generalized as follows: Class 1—safe under reasonably foreseeable operation (not accounting for unsafe operations, such as removal of safety precautions); Class 1M—generally safe, some precautions may be required; Class 2—visible light at low power (<20 mW), blink limits risks; Class 2M—emission of ULTRAVIOLET or infrared invisible light, generally safe, some precautions may be required; Class 3R(A)—safe for viewing with the unaided EYE (no optical devices allowed); Class 3B—hazardous, diffuse reflection may be safe; Class 4—hazardous under all conditions, hazardous to eyes and skin. Note that the eyes are the most vulnerable and will be protected under most any classification of laser, with the exception of laser pointers. Keep in mind older laser pointers (pre-2005) that are viewed straight on into the laser beam will cause retinal damage (see [Figure L.32](#)).

Interaction of electromagnetic radiation and atomic systems-1

- Assume an atomic medium is enclosed in a thermally isolated container at a temperature T
 - The atoms possess only two possible infinitesimally sharp energy states: W_u and W_i
 - Photon transitions occur between level u and i
 - Monochromatic radiation is absorbed between the two energy states, or subsequently emitted at frequency ν_{ui}

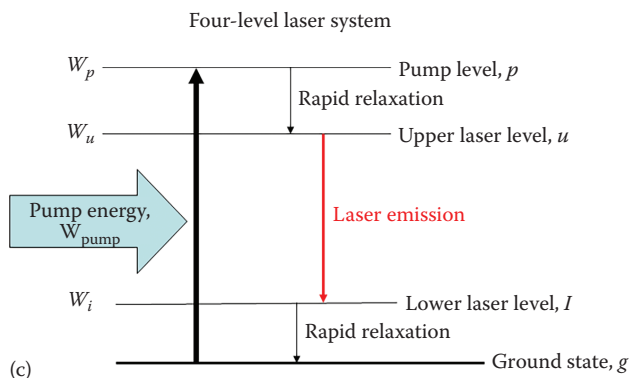
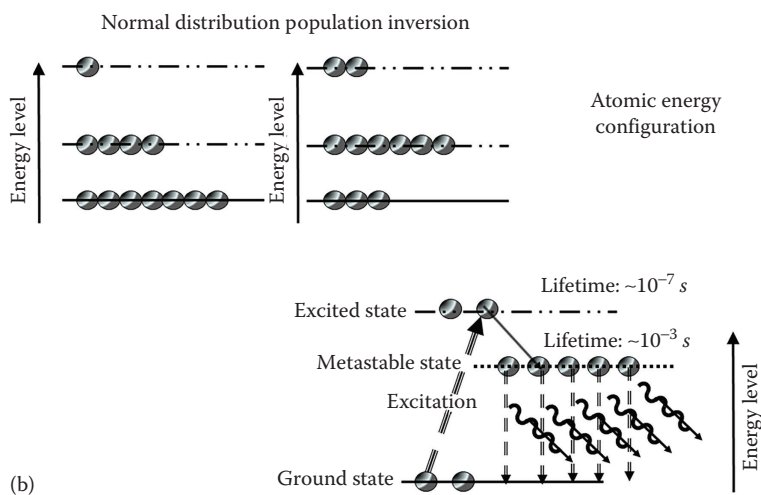
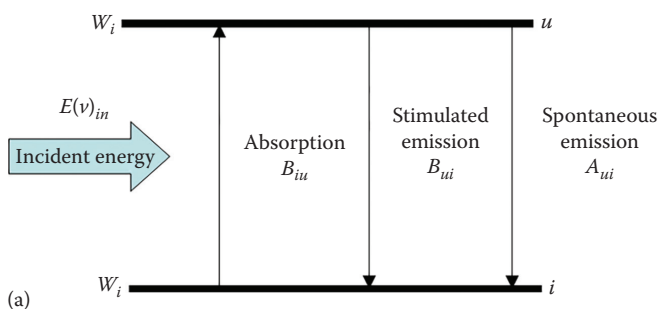
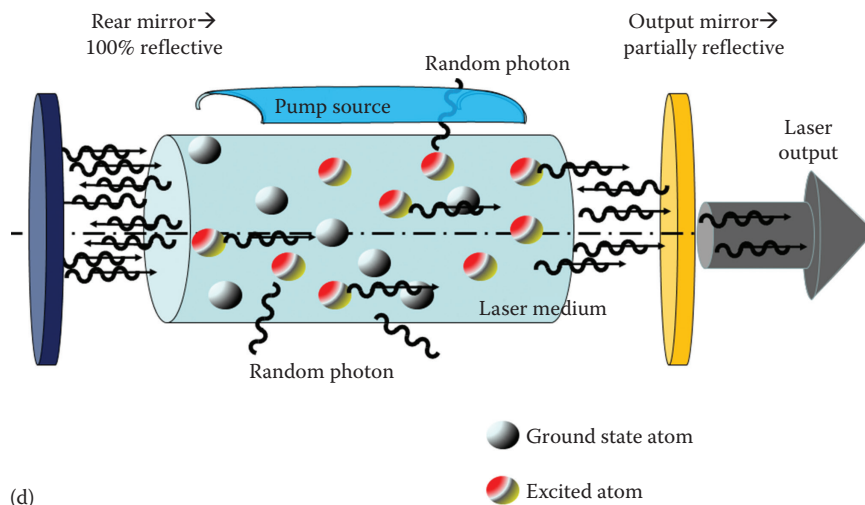
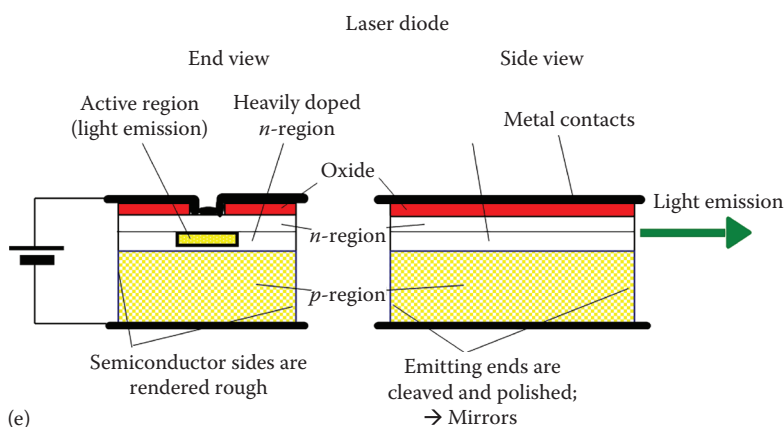


Figure L.32 (a–c) LASER examples and the mechanism of operation.

(Continued)



(d)



(e)

Figure L.32 (Continued) (d–e) LASER examples and the mechanism of operation.

Laser biostimulation

[biomedical, chemical, optics, thermodynamics] Mechanism of action using light to accelerate a biological process, specifically applied to healing of surface wounds. In particular, light is an ENERGY source that can be processed by tissue in similar fashion as found in trees, creating a form of PHOTOSYNTHESIS. Laser biostimulation can be used to induce chemical reactions as a catalyst as well. Also known as light biostimulation, or just biostimulation with reference to light. Additional nomenclature includes low-level laser therapy (LLLT), also known as 3LT, low-level light therapy or photomedicine. The early Egyptians (~100 BC) were aware of the potential for light in clinical use. Further applications were in the thirteenth century when the physician HENRI DE MONDEVILLE (1260–1320) used RED light in the treatment of smallpox. Since the inception/development of laser, the laser has been tested for every known affliction. It was not until the work of the more systematic approach by the Hungarian physician and surgeon Endre Mester (1903–1984) in 1967, who used ruby and helium–neon (He–Ne) lasers for studies in wound healing, that LLLT became a more established science with verifiable correlation to the use of light with respect to other treatment options and placebo. Methods applied to measuring the influence of light were either phenomenological (rate of cure—“subjective”), chemical (BLOOD or urine analysis), or ACTION POTENTIAL

rate/AMPLITUDE based as well as subjectively based on individual PERCEPTION. Light has been verified as a means to induce physiological effects. The most well-known is photosynthesis in plants and the production of vitamin D in mammals (only for the wavelength range: 280–320 nm). The main principle is that specific photons that have the potential for influencing the chemistry or physiology need to be absorbed to achieve a result. This means that the light penetrating into tissue will have a lower probability of inducing effects with greater depth due to attenuation resulting from both absorption and SCATTERING. Additionally, the proper wavelength (-range) needs to be administered in order to obtain the energy conversion appropriate for the desired results. The MAGNITUDE of applied light will also have a crucial impact on the final outcome, too much fluence may cause adverse effects, whereas too little will not achieve any effects. However, most photobiological effects are cumulative, placing the constraints on the exposure duration as well as the radiant fluence. One specific example is that it is safe to irradiate the cellular DNA with “blue” light, since DNA does not have the mechanism to convert this energy (although ULTRAVIOLET light will), while bilirubin is most definitely susceptible to blue light. Blue light changes bilirubin (yellow breakdown product of normal heme catabolism; blood) into a form that the baby can more easily get rid of in his or her stool and urine, a condition affecting approximately 70% of newborns (jaundice). Phototherapy treatments decrease the bilirubin levels in the blood by changing the *trans*-bilirubin into *cis*-bilirubin isomer, which is water soluble. Applied light within the wavelength range 390–470 nm is highly effective, whereas green light (530 nm) is not only ineffective for production of the photoisomer, but capable of reversing the reaction and may hence be considered harmful. The QUANTUM yield of the light irradiation is the product of the PROBABILITY that the light will be absorbed (function of action spectrum) and the probability that the delivered cumulative amount of light will induce a chemical or physiological reaction. The action spectrum provides the relative efficacy of light at certain wavelengths to achieve a biological response. The spectral response depends on the effective chromophores involved. The CHROMOPHORE is required to mediate the energy conversion aspect in any irradiation process, whether this would be chemical or thermal. Mechanism of action. The light interaction with biological media can be classified under four specific mechanisms that rely of unique individual physical, chemical, and physiological principles. The four areas are as follows: (1) The interaction on a cellular level, with the cellular components; split further in metabolic (i.e., cellular components and chromophores) and functional (i.e., membrane; gates/transmembrane potential/cellular communication) interaction. (2) On a tissue structure and function basis, whole tissue effects. (3) Chemopsychological influences. (4) And lastly, psychosomatic aspects. The cellular chromophores responsible for the effect of visible light on mammalian cells, including cytochrome c oxidase (with absorption peaks in the near infrared) and photoactive PORPHYRINS. Mitochondria are thought to be a likely site for the initial effects of light, leading to increased ATP production, modulation of reactive oxygen species, and induction of transcription factors. These effects in turn lead to increased CELL proliferation and migration (particularly by fibroblasts); modulation in levels of cytokines, growth factors, and inflammatory mediators; and increased tissue oxygenation. In the cells the chemical ACTIVITY can be found in the NUCLEUS and the MITOCHONDRIA of cells. Certain proteins, such as NADH-dehydrogenase (i.e., flavoprotein, yellow in COLOR), can work as photoacceptors in a similar fashion to chlorophore. Additional “regenerative” influences involve the stimulation of the fundamental cellular building blocks DNA and RNA into division, increasing the cell multiplication process. Furthermore light-induced serotonin breakdown to alleviate pain can be verified through the excretion of the chemicals resulting from the production of 5-hydroxyindole acetic ACID under irradiation by 632 nm light (helium–neon laser). Specific cellular MEMBRANE gates/channels are influenced on their DIFFUSION rate by irradiation with light. One specific example is the light-mediated diffusion through the PTPV1 membrane gate. For this particular channel, the sensitivity to light has been shown to be very specific, no response under irradiation by either 406 or 635 nm, but only changes due to 532 nm. Additionally, cell signaling, cellular communication by means of light has been documented and also shows potential for light-mediated cellular activity. On a MACROSCOPIC level the interaction between the chemical: nitric oxide (derived through chemical interaction within human digestion from ingredients found in beets)

with resulting light-mediated vasodilation aspects are well documented. On a more general platform tissue warming by infrared light is used on a daily basis by radiative heaters such as electric heater coils for whole-house heating as well as by sunlight. Infrared light up to 1900 nm has deep tissue penetration and the potential to be used for deep tissue heating. Infrared lamps used in the prepared meat section of the grocery store and fast-food chains are an example of this as well as heat-lamps used to treat **MUSCLE** aches. Longer wavelengths are absorbed on surface impact. On a psychological level, mood and behavioral changes have been induced with measurable chemical outcome resulting from irradiation of **SKIN** areas that were not in the proximity of the **EYE**, in order to avoid the visual psychological impact. Examples are the “treatment” of “winter blues” and inducing changes to the circadian rhythm, in particular beneficial to long-distance travelers. On the skin surface almost all highly vascularized areas are susceptible to the influence of light to induce modulate behavior (influence the effects of “jet lag”) and mood (“depression”), first discovered for the area behind the knee (“popliteal fossa”). Sleep pattern changes under the influence of light have been quantified by REM sleep **PHASE** occurrence and durations. Research has demonstrated that nighttime light exposure suppresses the production of melatonin, the major hormone secreted by the pineal gland that controls sleep and **WAKE** cycles. Therefore, a reduction in melatonin at night is associated with subjective levels of sleeplessness. Short wavelength light (446–477 nm) has been linked in particular with a reduction in melatonin. Studies have shown that one hour of moderately bright light exposure (1000 lux) was sufficient to suppress nocturnal melatonin to daytime levels. This also indicates that the exposure to blue light during the day may result in more alert daytime activity. This last statement is underscored by the science behind the selection of room light spectral profile in offices. The psychosomatic effects of light, induced based on visual **PERCEPTION**, affect the following. Behavioral and mood changes resulting from light within certain wavelength bands when observed by the eye. The color of room lighting is a phenomenon that is directly or indirectly experienced by the observer “mood lighting” versus “blue tone” light when concentration is required. A clear sky has a “color temperature” of approximately 10,000 K, which peaks at 300 nm as defined under Wien’s law. Room lighting can be “tuned” to the desired needs based on commercial luminescent bulb selection (see [Figure L.33](#) and [Table L.1](#)).

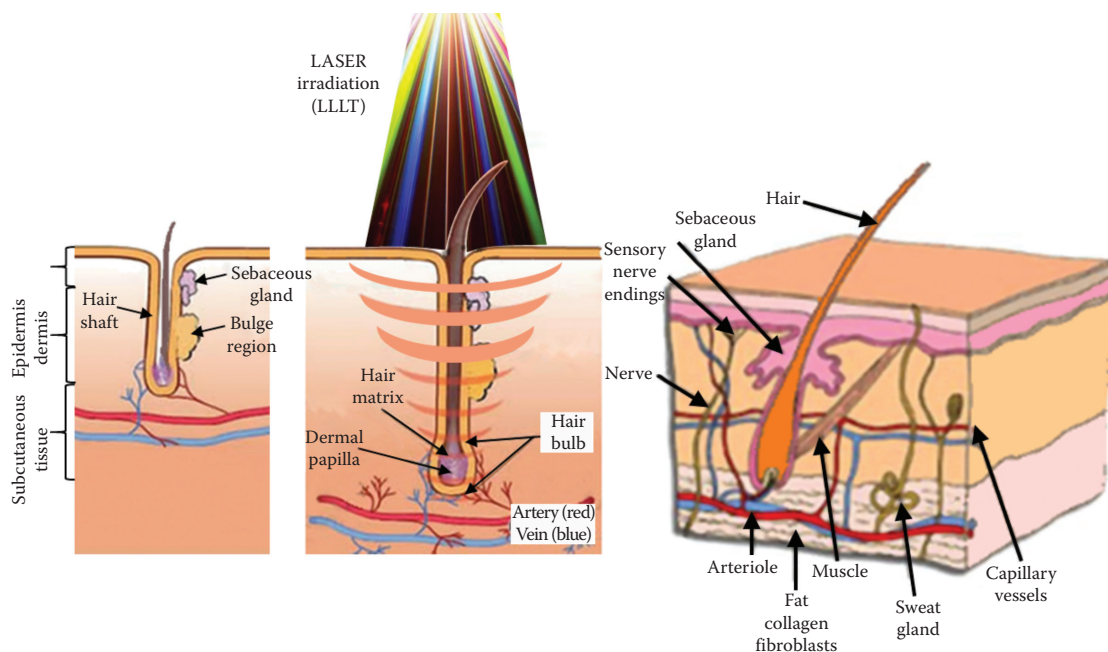


Figure L.33 Examples of laser biostimulation.

Table L.1 Overview of low-level light therapeutic procedures and the alternatives available to the consumer (e.g., procedure or over-the-counter vs. by prescription)

APPLICATION	WAVELENGTH RANGE (NM)	COMPETING TECHNOLOGIES
Acupuncture	630, 780	Needle
Alzheimer's	632	Nicotine/medication
Blood flow	410–420 nm, 540–550 nm, and 570–580 nm Pulse pause & 310 nm (with NO)	Capzasin (muscle rub)
Brain function, recovery	665, 808, 910	Exercise
Bone generation	830	Steroids, exercise
Carpal tunnel	830	Steroids/exercise
Circadian rhythm (jet lag)	446–477 nm	Behavioral routines, oxygen, “illicit drugs”
New: Claudication pain	310 + beet juice	Massage
Collagen/cartilage	900; 1064	NA
Dentistry (heal/pain)	632, 660, 830	Tylenol, ibuprofen
DNA genetic aberration	<260 modify DNA (carcinogenic)	X-ray
DNA → cell division	400, 620, 680, 760 and 825 nm	NA
New: Fetus in womb	Red–Near-IR	Music to the baby
Hair growth	635	Rogaine
Jaundice	390–470	NA
Joint (horse)	1064	NA
Laser “acupuncture”	808 nm	Needle acupuncture
Membrane gate (TRPV1)	532	Medication
Memory	632; 1064	NA
Mood (winter blues)	Blue	Medication
Muscle relaxation	808, 810 nm	Ben-gay, massage, sauna
Muscle—Greyhound	808; 810; 830	Massage
Nerve (“pain”/dysfunction)	830	Medication
Oral mucositis	632; 660; 830	Chemotherapy or medication
Osteoarthritis	Several wavelengths; no effect	NA
REM sleep	446–477 nm	Medication
Pain	808; 810; 900	Medication
Peripheral neuropathy	665, 810, 904	Acupuncture
Psoriasis	310, UV	Ointment/medication

(Continued)

Table L.1 (Continued) Overview of low-level light therapeutic procedures and the alternatives available to the consumer (e.g., procedure or over-the-counter vs. by prescription)

APPLICATION	WAVELENGTH RANGE (NM)	COMPETING TECHNOLOGIES
Rhinitis	650	
Spine	(polarized)	Physical therapy
Sport injury (joint)	808, 810 nm	Rest
Tissue warmer (human/pet)	Near-IR, broadband	Electric blanket (conductive)
Vasodilation: blood perfusion	310 (+NO)	Hormones/medication
Vitamin D	280–320	Sun-tan bank, vitamin supplement
Weight loss	635	Exercise/liposuction
Wound healing	632	Steroids (ingested/topical)

Laser Doppler

[biomedical, fluid dynamics, general, mechanics, optics] Due to the coherence of the laser source the wavelength and time are extremely well defined, lending it to the process of INTERFERENCE for diagnostic purposes. DOPPLER shift occurs as a result of the MOTION of the secondary source, which now will be the REFLECTION from a component in the path of the incident laser beam. Measuring the Doppler shift allows for accurate and noninvasive determination of the MAGNITUDE and direction of the velocity of objects, such as checking for the velocity of an automobile by law enforcement or the localized BLOOD flow velocity in an organ, resolved by blood vessel (averaged). Combining the laser Doppler mechanism with coherence TOMOGRAPHY can provide RESOLUTION within the blood vessel to establish a FLOW velocity profile (see Figure L.34).

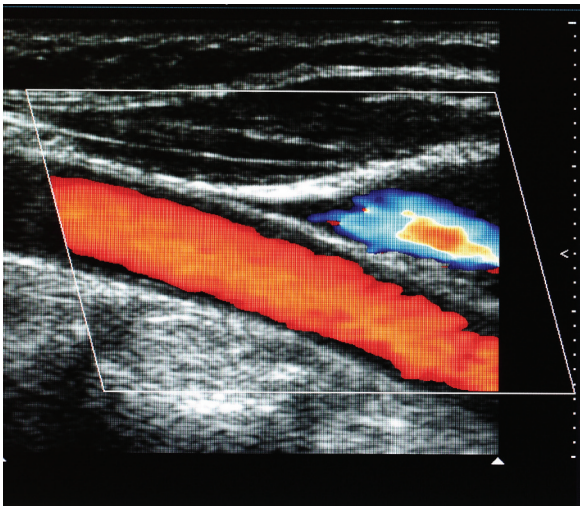


Figure L.34 Application of Doppler velocity measurement in human carotid artery. The velocity magnitude, and respective direction with respect to the probe (positive → “toward”; or negative ← “away”) is represented in false color.

Laser Doppler anemometer

[fluid dynamics] As the ANEMOMETER is used to determine the velocity of wind by mechanical means in the location of the device, the use of laser will provide the opportunity to determine the wind direction and velocity at great DISTANCE from the device. The mechanism of action is the basic DOPPLER principles, his time using the DISPERSION in the AIR density resulting from atmospheric flow.

Laser holographic interferometer method

[computational, fluid dynamics, optics] The concept of taking advantage of the WAVE attributes of electromagnetic containing phase (ϕ) information in three-dimensional IMAGE reconstruction was initially suggested in 1948 by the Hungarian scientist DENNIS GABOR (1900–1979). It was not until the introduction of the coherent laser light that phase-sensitive representations could be stored on photographic plate and be used for virtual visual three-dimensional reconstruction. Specifically the coherence of the laser makes it ideally suited to perform the INTERFERENCE pattern construction with a high degree of accuracy. The holographic mechanism recombines scattered light from an object with a reference beam that is generated by splitting a laser beam in two components in an INTERFEROMETER design, such as a MICHELSON INTERFEROMETER. The scattered light will have a phase-shift $L_2 = L_{02}e^{i\phi_2}$ with respect to the incident and reference light $L_1 = L_{01}e^{i\phi_1}$, where the PHASE shift is captured as $\Delta\phi = \phi_2 - \phi_1$, yielding the interference at the converging point of the interferometer (e.g., the PHOTOGRAPHIC PLATE), expressed as the intensity, or respectively the degree of photographic emulsion darkening as $I = 2L' \{1 + \cos(\Delta\phi)\}$, assuming little difference in incident and scattered RADIANCE ($L' = L_{01} = L_{02}$), the phase difference is related to the path length traveled as $\Delta\phi = kd(\cos\theta_1 + \cos\theta_2)$, where $k = 2\pi/\lambda$ the wavenumber, with λ the wavelength, d the DISTANCE, and θ_1 and θ_2 , respectively, the ANGLE on incidence with the SCATTERING object and the scattering angle of the detected ray, providing positive and negative interference based on the path length difference in multiples of half-wavelength. In reconstruction a broadband source can be used to generate the optical illusion of a three-dimensional object using stereoscopic VISION (*also see INTERFEROMETRY*) (see Figure L.35).

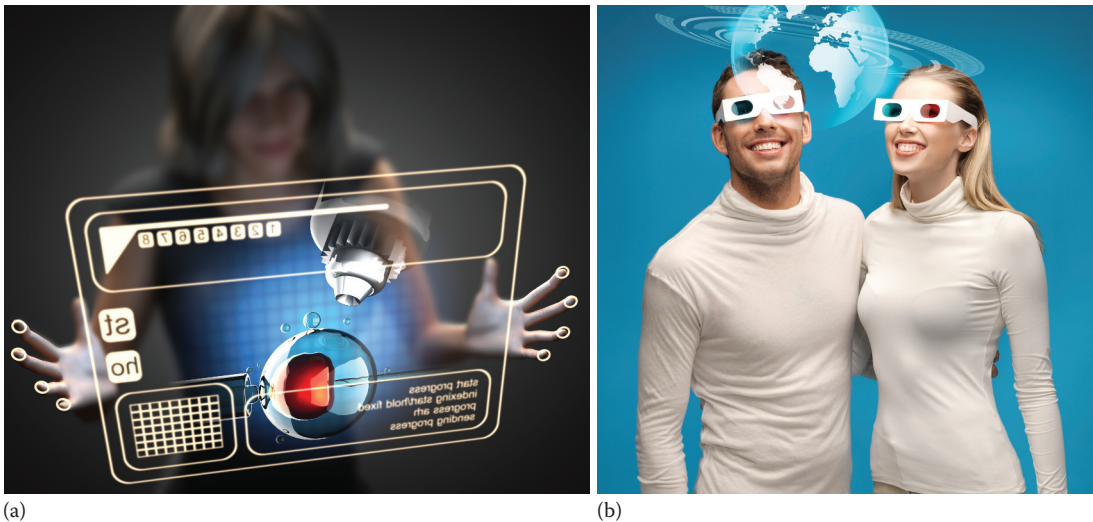


Figure L.35 (a) Laser holographic interferometer method used during three-dimensional guidance for artificial insemination and (b) holographic image viewing in free-space, futuristic, but not too far away in the future.

Laser scanning confocal microscopy (LSCM)

[biomedical, optics] Scanning laser microscope where both light delivery and detection for a three-dimensional semitransparent object are controlled by means of the focal length of LENS that can be translated to and fro with respect to the object, hence providing a slice algorithm used to section the object in parallel planes. The axial RESOLUTION is a direct function of the NUMERICAL APERTURE of the lens. The LSCM focuses the probing light as well as the imaging plane at a certain level and uses APERTURES to reject the out-of-focus rays in order to enhance contrast and resolution. Scanning in a preset pattern in a single plate provides the digital information to reconstruct each individual plane and form a three-dimensional image. The basis of the scanning microscope is provided by a conventional optical MICROSCOPE, adapted for step-wise scanning in x , y , and z directions by means of servomotor control, or stepper motors. The illumination has been replaced by laser beam to ensure selective and focused illumination of the region of interest. Generally, more than one laser is used to provide spectral-based analysis. Certain aspects of the object may be more visible, higher contrast than other characteristics under narrow band illumination. The use of a dichroic scanning MIRROR allows for wavelength-specific illumination in scanning fashion. Each laser is fitted with the specific dichroic mirror for optimal scanning discrimination. The use of an aperture in line with the imaging lens will reject all out-of-focus light, providing the confocal aspect. The specimen can additionally be tagged with fluorescent probes to identify certain characteristic features, anatomical structures, and chemical signatures. The fluorescent imaging also applies to immunofluorescence imaging, providing the ability to highlight certain proteins. The IMAGE formation is radiance (intensity) based only, at the respective wavelengths. The SIGNAL acquisition uses either a PHOTOMULTIPLIER tube or pin-diode detector for the location-specific radiance. LSCM offers the following advantages: (1) higher resolution images than conventional microscopy (greater than twofold improvement in LATERAL RESOLUTION), (2) higher magnification than conventional microscopy, (3) generation of three-dimensional images, and (4) it minimizes diffraction influences, rejecting stray light due to the small dimension of the illuminating spot and target in the FOCAL PLANE. LSCM is still limited in resolution because this is still linked to the properties of light itself. The confocal microscope offers opportunities for frequent, repetitive (hours or days in between scans) quality control without the need for disassembly of the specimen, as is required for conventional microscopy. The repetitive scanning is in particular useful for biological CELL growth, specifically with respect to regenerative MEDICINE (see [Figure L.36](#)).

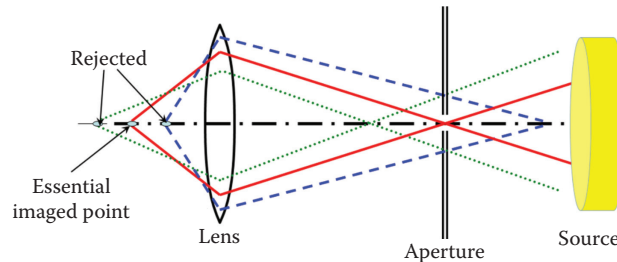


Figure L.36 Laser scanning confocal microscope.

Laser speckle method (LSM)

[fluid dynamics, optics] The scatter/reflection of the coherent laser light from a rough surface generates a granular light distribution pattern called a speckle pattern. The speckle pattern results from the INTERFERENCE of multiple waves with respective random individual phases. The spatial interference pattern observed is a direct function of the laser spot size (D) and the DISTANCE from the object (z) as well as the laser WAVELENGTH (λ) yielding a fringe pattern frequency: $\nu_{\text{fringe}} = D/\lambda z$, and respective spacing:

$\sigma_{\text{speckle}} = 1/\nu_{\text{fringe}} = \lambda z/D$ (see [Figure L.37](#)).



Figure L.37 Laser scanning speckle surface contour tracing for thirteenth century wood carving. (Courtesy of LASer & Electro optical Research in engineering metrology, Università degli Studi dell'Aquila, L'Aquila, Italy.)

Latent heat

[general, thermodynamics] The heat required to accomplish a PHASE TRANSITION; solid $\leftrightarrow$ liquid, liquid $\leftrightarrow$ vapor, while the medium remain at constant temperature. The following versions of latent heat are used: latent heat of FUSION (heat released to solidify a LIQUID), heat of sublimation (HEAT TRANSFER to accomplish transfer from solid to VAPOR), and heat of vaporization (ENERGY to vaporize liquid).

Latent heat of fusion (L_f)

[general, thermodynamics] The quantity of HEAT (Q) exchanged per unit mass (m) required to liquefy a solid object while maintained at its melting temperature: $Q = \pm m L_f$. (Note: Reversible: $\pm$) (also see HEAT OF FUSION).

Latent heat of sublimation

[general, thermodynamics] The quantity of heat exchanged per unit mass required to vaporize a solid object while at its melting temperature (also see HEAT OF SUBLIMATION).

Latent heat of vaporization

[thermodynamics] The quantity of heat exchanged per unit mass required to change a LIQUID object into VAPOR while at its boiling temperature (also see HEAT OF VAPORIZATION).

Lateral resolution

[acoustics, optics] The ability to distinguish two points adjacent to each other. In ACOUSTICS, the RESOLUTION to separate two objects that are at a horizontal DISTANCE d is a function of the imaging WAVELENGTH (λ), the APERTURE of the source (D), and the focal length of the acoustic generation mechanism (f): $d = \lambda f / D$. In OPTICS, the discrimination is $d \cong 1.22 \lambda f / D$, (the airy disk radius, as generated by the diffraction pattern; the IMAGE of object 2 needs to fall in the first minimum of the diffraction pattern of the INTERFERENCE pattern generated by

the imaging system for object 1) which is often defined as the ANGLE (θ_{res}) between the rays emitted to the observer from two adjacent objects: $\theta_{\text{res}} \cong 1.22\lambda/D$ (also see **RAYLEIGH CRITERION**, **RESOLVING POWER**, and **AIRY DISK**).

Latitude

[geophysics] The angular position of the circumventing indicator on the globe of a PLANET with respect to the meridian/equator, which is half way between the POLES of rotation (North–South). This compared to the longitude, measured with respect to the Greenwich line running North–South, describing the location in the circumference combined yields the means to locate a land mass, ship, or house on a street (also see **GLOBAL POSITION SYSTEM**). There are several regions demarcated by latitude, the tropics, subtropics, midlatitude (Europe, Central and northern Asia, North America, Australia), and next to the polar regions (NORTH and South Poles, respectively, on the northern and southern hemispheres). Latitude also applies to marking out the celestial configuration, markedly the Big Dipper is only visible on the northern hemisphere (see [Figure L.38](#)).



Figure L.38 The geographic latitude of Earth at 15° intervals with respect to the equator in geometric frame of reference.

Latitude effect

[nuclear] The observed cosmic radiation appears to be relatively constant when measuring as a function of LATITUDE. Below a latitude of 50° , moving from the North Pole to the equator there is a sudden decrease, with a minimum at the equator, from where the detected MAGNITUDE increases while scanning the southern hemisphere to level off again at 50° latitude toward the South pole. This observation was made by ARTHUR HOLLY COMPTON (1892–1962) and colleagues, and published in 1930. Later investigations show that there is a reduced cut-off ENERGY for cosmic ray particles toward the POLES, while at the equator the energy cut-off for protons is 15 GeV and at the 50° HELIOGRAPHIC LATITUDE this has been reduced to 2.7 GeV; for perpendicular incident rays. This phenomenon may be correlated to the asymmetry of the MAGNETIC shell (see Figure L.39).

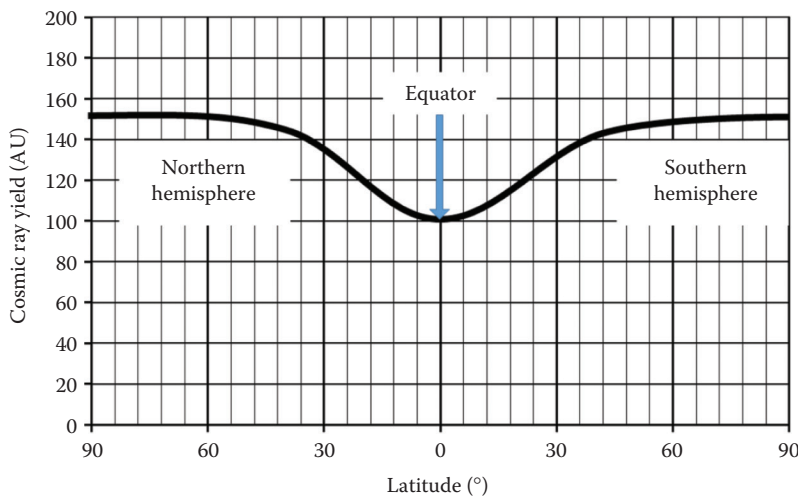


Figure L.39 Quantification of the latitude effect, illustrating the drop-off in cosmic radiation between 15° northern latitude and 50° southern latitude, with a minimum at the earth's equator.

Lattes, César Mansueto Giulio (1924–2005)

[atomic, nuclear] Brazilian nuclear physicist and scientist. Lattes is most known for the team effort in resolving the MUON enigma. In 1947, the discovery of the PION and the derived elementary PARTICLE muon was published by César Lattes with credits to GIUSEPPE OCCHIALINI (1907–1993) and CECIL FRANK POWELL (1903–1969). The observation was made on photographic plates doped with additional boron, tracking the trajectory of the cosmic ray particle path while in the Bolivian Andes mountains at an altitude

of 5500 m. In 1947, Lattes managed to produce a pion by colliding ALPHA PARTICLES on carbon atoms in the CYCLOTRON at University of California Berkley (see [Figure L.40](#)).



Figure L.40 César Mansueto Giulio Lattes (1924–2005). (Courtesy of Leonado dos Santos Vaz.)

Lattice

[atomic, chemical, solid-state] Regular arrangement of ions, molecules, or atoms in a two- or three-dimensional structure with specific chirality (i.e., symmetry). The lattice structure is the result of the chemical bonds between the respective constituents. The grouping results in a crystalline structure outlined by a total of 11 axes of symmetry, five (5) monaxial point groups (0° ; 180° ; 120° ; 90° orthorhombic; 60°) in additional six (6) polyaxial point group sets (4 dihedral set; 1 tetrahedral set; and 1 octahedral set). The crystalline structures available are as follows: ISOMETRIC or cubic, with three orthogonal vectors of equal MAGNITUDE; tetragonal, with three orthogonal vectors only 2 of equal magnitude; orthorhombic, defined by three orthogonal vectors all of unequal magnitude; hexagonal, defined by two equal magnitude vectors at 60° ANGLE with each other and a third unequal in magnitude at perpendicular angle; monoclinic, outlined by three vectors of different magnitudes of which only 2 are perpendicular; trigonal, defined by three equal vectors that are at equal angles with each other however not perpendicular; triclinic, outlined by three vectors of unequal magnitude at angles that are nonconforming between respective pairs (*also see* **BRAGG PLANE** and **BRAVAIS LATTICE**) (see [Figure L.41](#)).

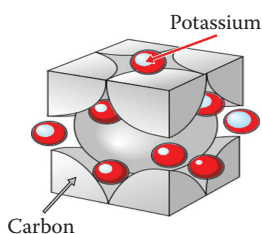


Figure L.41 Lattice structure. Graphene lattice.

Lattice array

[atomic, condensed matter, solid-state] Structural configuration of components, often applied to dipoles, in a repetitive pattern. A very simple lattice array is a triangle.

Lattice constant

[atomic, condensed matter, solid-state] Characteristic length separating two adjacent constituents in a LATTICE structure (see [Figure L.42](#)).

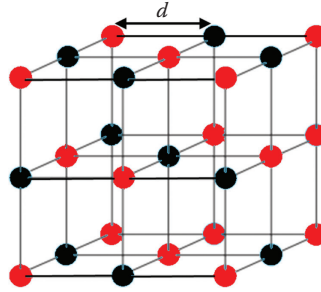


Figure L.42 Illustration of the lattice constant for a lattice.

Lattice factor

[atomic, condensed matter, solid-state] As electrons are scattered while interacting with a LATTICE the equation of MOTION provides a WAVE function (Ψ) for the electron motion resulting from interaction with respective lattice constituents x_i at a random location $\vec{r}$: $\Psi_i(\vec{r}) = \Psi_0 e^{i(\vec{k}_i - \vec{k}_f) \cdot \vec{R}_i}$, with intensity $I = |\Psi|^2$, where $\vec{k}_i = 2\pi/\lambda_i$ is the incident wave vector, λ the wavelength, $\vec{R}_i = m_i a_1 + n_i a_2$ the vector outlining the structure of the unit CELL in the lattice with respective lattice constants a_1 and a_2 , m_i and n_i constants, and $\vec{k}_f$ the outgoing wave-vector. This results in the following conversion: $I = |\Psi|^2 = |\sum_i \Psi_i|^2 = |\sum_{j=1}^J \Psi_{0j}|^2 \times |\sum_{i=1}^N e^{i(\vec{k}_i - \vec{k}_f) \cdot \vec{R}_i}|^2$, where the first term represents the summation over all constituents ($|\sum_{j=1}^J \Psi_{0j}|^2$, the “structure factor”) and the second term is the sum over all the lattice cells, the lattice factor. The lattice factor is the determining factor in the analysis of the projected (single-) scattered electron pattern on the screen.

Lattice plane

[atomic, condensed matter, solid-state] Intersecting plane of a LATTICE that can be duplicated in parallel pattern to describe the three-dimensional lattice structure. Also considered the repetitive structural pattern of connected components at regular intervals, illustrating the symmetry of the pattern of lattice components (see [Figure L.43](#)).

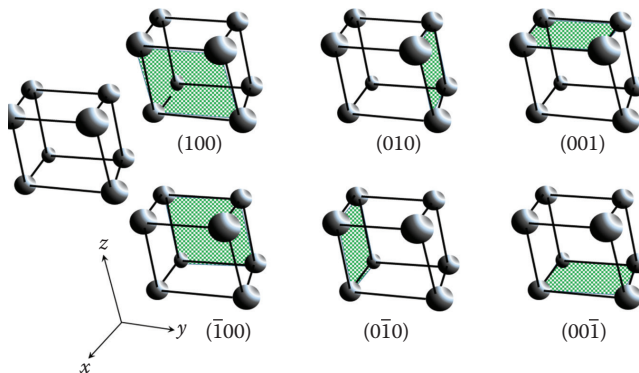


Figure L.43 Definitions for the six specific lattice plane configurations.

Lattice spacing

[atomic, condensed matter, solid-state] See LATTICE CONSTANT.

Lattice theory

[computational] Mathematical methods that apply to functions and phenomena with symmetry and order. Lattice theory is often applied in Boolean theory.

Lattice vibration

[acoustics, atomic, condensed matter, solid-state] Vibrations of a lattice structure generating a pressure wave. Due to the strong bonds in the regular pattern the individual MOTION of components is directly coupled to the neighboring components in the LATTICE. The vibrations in a regular lattice under the influence of harmonic forces between components induce, as a normal mode, lattice waves. Due to the potentially anisotropic nature of the crystal the WAVE propagation can be subject to DISPERSION. Lattice wave can range in frequency from several Hertz to above and beyond 10^{13} Hz. Lattice vibrations can have several POLARIZATION directions, depending on the crystalline structure. (see Figure L.44)

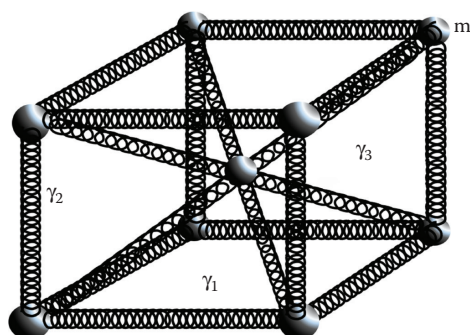


Figure L.44 Outline of the configuration supporting lattice vibrations.

Laue, Max Theodor Felix von (1879–1960)

[general, optics, solid-state] Physicist from Germany. Von Laue discovered X-RAY diffraction by crystal structures supported by the efforts of Walter Friedrich (1883–1968) and PAUL KNIPPING (1883–1935). This research was based on the recognition of X-ray RADIATION by WILHELM CONRAD RÖNTGEN (1845–1923) in 1895 and 1901. This discovery lead to the Bragg GRATING and molecular crystal structure analysis. Max von Laue was awarded the Nobel Prize in Physics for his work in 1914 (see Figure L.45).



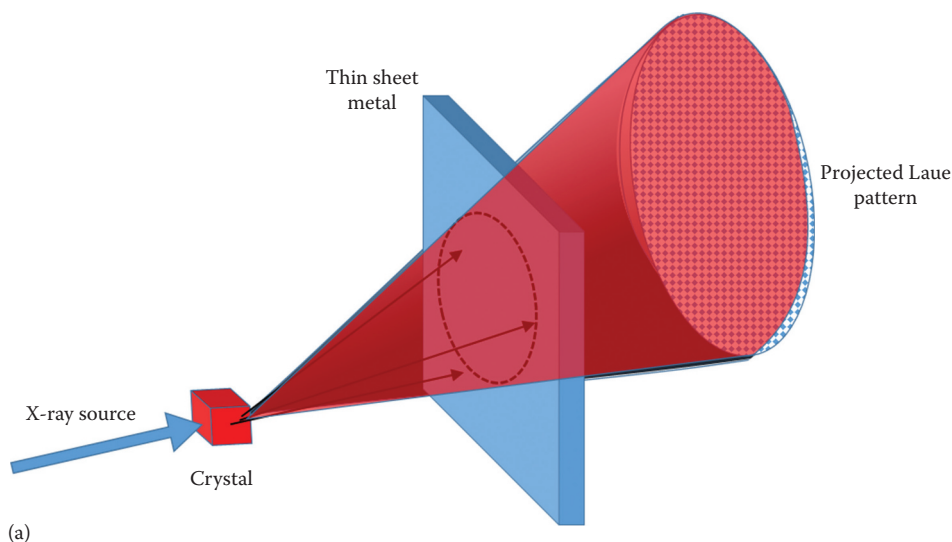
Figure L.45 Max Theodor Felix von Laue (1879–1960). (Courtesy of German Federal Archive. <http://www.iucr.org/pub/50yearsofxraydiffraction/full-text/von-laue>.)

Laue diffraction pattern

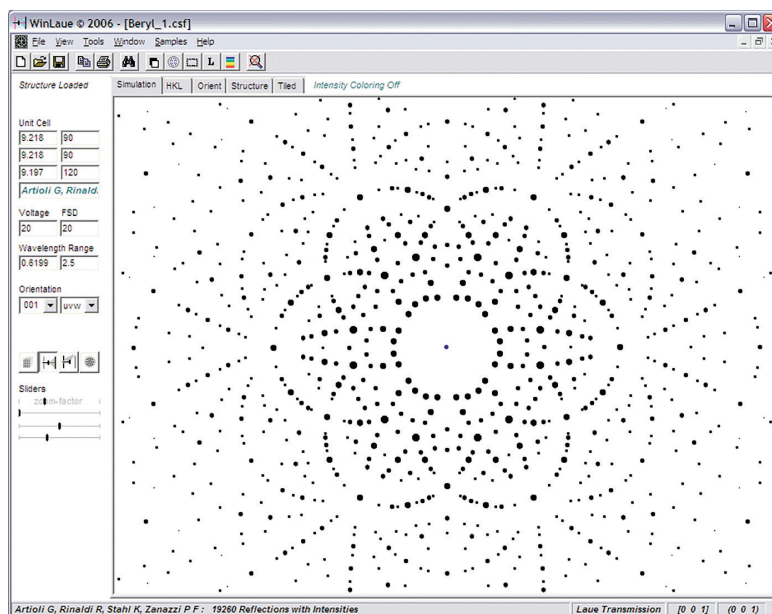
[atomic, nuclear, solid-state] See LAUE PATTERN.

Laue pattern

[imaging, nuclear] Line diffraction pattern generated by X-RAY transmission through a crystal. Based on the projected diffraction pattern the three-dimensional crystalline structure and ENERGY configuration can be determined, similar to an optical diffraction pattern such as the dual-slit experiment. The crystal acts as a three-dimensional DIFFRACTION GRATING, specifically under irradiation by an extremely narrow X-ray beam (*also see* LAUE DIFFRACTION PATTERN) (see Figure L.46).



(a)



(b)

Figure L.46 (a) Experimental design of the collection of the X-ray diffraction pattern using the Laue technique with narrow beam of X-ray photons incident on a thin sheet of metal. (b) X-ray diffraction simulation: Laue pattern. (Courtesy of Steffen Weber with J. Cystal.)

Laue technique

[atomic] X-ray scattering technique as introduced by MAX VON LAUE (1879–1960) using large crystals or crystal-powder for the recording of the Laue X-RAY diffraction patterns. The crystals can be vibrated or rotated to induce perturbation for enhanced contrast.

Lauritsen, Charles Christian (1892–1968)

[atomic, nuclear] Physicist from Denmark. Lauritsen's work includes the development of high-energy X-RAY emitters used for cancer therapy. A discovery made during bombarding the NUCLEUS of carbon atoms with protons illustrated how gamma rays could be generated artificially (see [Figure L.47](#)).



Figure L.47 Charles Christian Lauritsen (1892–1968).

Lauterbur, Paul Christian (1929–2007)

[biomedical] Chemist from the United States. Lauterbur's work involved the development of MAGNETIC resonance imaging, by configuring magnetic fields with gradients in three dimensions in order to create a mechanism for three-dimensional reconstruction, by means of providing spatial encoding. These principles were later refined by Richard Robert Ernst (1933–) by modulating the magnetic fields as a function of time, the basis of modern MRI (see [Figure L.48](#)).



Figure L.48 Paul Christian Lauterbur (1929–2007). (Courtesy of Joan Dawson.)

Laval nozzle

[fluid dynamics] Converging–diverging nozzle design introduced by CARL GUSTAF PATRIK DE LAVAL (1845–1913) in 1893. The throat of the NOZZLE is designed so that the gas FLOW reaches supersonic velocities. The concept primarily applies to incompressible fluids (see [Figure L.49](#)).

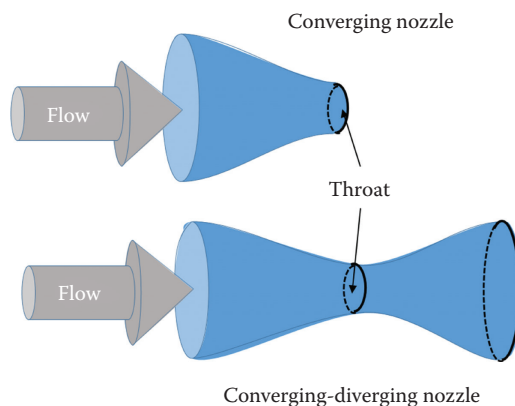


Figure L.49 Laval nozzle.

Lavoisier, Antoine-Laurent de (1743–1794)

[biomedical, chemistry, mathematics] Scientist, chemist, and economist from France (he also studied law) who has been attributed to naming the ELEMENTS oxygen in 1777 and carbon in 1789. Lavoisier stated the elementary definition of an ELEMENT as a material that cannot be split into more elementary components with the same unique chemical properties. In total Lavoisier may have verified the existence of roughly 40 elements. The description of oxygen coincides with the work of JAN INGEN-HOUSZ (1730–1779) on PHOTOSYNTHESIS. Alternatively, until then carbon was known as graphite, which was used in pencils at the time of the disclosure in 1594 by D.L.G. Harston and A.G. Werner, but had been known for centuries as a marking tool. Lavoisier is often referred to as “the father of modern chemistry.” The work of Lavoisier illustrated the regular binding patterns of elements to form products, such as SALT, water, and alcohols (see [Figure L.50](#)).



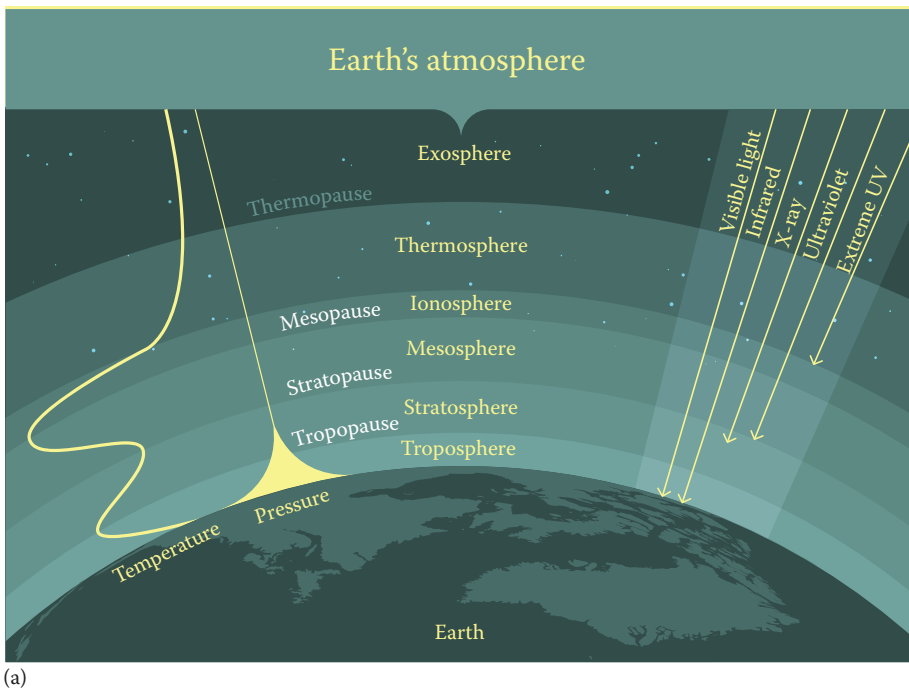
Figure L.50 Antoine-Laurent de Lavoisier (1743–1794). (Courtesy of C.E. Wagstaff in 1835.)

Law of angular momentum

[nuclear] The rotation of the electron-spin angular momentum ($\vec{J} \Rightarrow$) converges for infinitesimal rotations to $\vec{J} \times \vec{J} = i\vec{J}$ (see ANGULAR MOMENTUM).

Law of atmospheres

[geophysics, general] The PRESSURE (P) as a function of altitude (z) in a planet's ATMOSPHERE can be defined as $P(z) = P_0 e^{-mgz/k_B T}$, where m is the average molecular mass of the gaseous composition, $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann constant, P_0 the reference pressure, and g the GRAVITATIONAL ACCELERATION. This is also known as the BAROMETRIC LAW (see ATMOSPHERE) (see Figure L.51).



(a)

Figure L.51 (a) Graphical representation of the law of atmospheres.

(Continued)



(b)

Figure L.51 (Continued) (b) atmospheric view of conditions above the mainland England and Ireland, and the western edge of France.

Law of conservation of angular momentum

[general, mechanics, thermodynamics] In a rotational system of particles (e.g., solid as well) where there is no net torque applied will have no loss of the total sum of angular momentum around a fixed point of reference. Note the rate of change in ANGULAR MOMENTUM (L) is equal to the applied net TORQUE (τ): $dL/dt = \tau$ (see ANGULAR MOMENTUM).

Law of conservation of charge

[energy, general, solid-state] For an ISOLATED SYSTEM charge cannot be created or destroyed. The total charge of closed system will remain the same. This may elude to the fact that the total charge of the UNIVERSE equals zero, but there is currently no mechanism available to verify this hypothesis.

Law of conservation of energy

[fluid dynamics, thermodynamics] In any ISOLATED SYSTEM (i.e., no external forces) the sum of all ENERGY forms remains constant. The forms of energy can, for instance, be work (W), potential energy (U), kinetic energy (KE), CHEMICAL ENERGY (E_{chem}), and electrical energy (E_{elec}). Please note that according

to Einstein's theory (ALBERT EINSTEIN [1879–1955]) MASS (m) can be a form of energy as well ($E = mc^2$, where c is the speed of light). The early principles of the concept of CONSERVATION OF ENERGY date back a long time, maybe even old Greek philosophers, but was expressed in a general form by WILLIAM RANKIN (1820–1872) in 1853. In a process the energy contribution of all different thermodynamic properties are included in the balance: kinetic and potential energy of a process, heat, electrical energy as well as chemical energy. Some energy contributions can be on the atomic or molecular scale, and there is a means of conversion between all energy contributions, for instance but not limited to: chemical to kinetic or heat, electrical to mechanical or heat, but the sum of all energy constituents remains constant in any process.

Law of conservation of mechanical energy

[general] This conservation law only focuses on the KINETIC ENERGY (KE) and potential energy (PE) of a process, there is neither heat, electrical energy nor CHEMICAL ENERGY or any other form of energy involved at this point: $KE_1 + PE_1 = KE_2 + PE_2$, where the subscript identifies the state of the process. The general LAW OF CONSERVATION OF ENERGY does, however, include all forms of energy.

Law of conservation of momentum

[general] A system in MOTION will remain in motion at the same velocity when there are no external forces (F). The system will be comprised of units of mass (m_i) with respective velocity (v_i) yielding the momentum $\vec{p} = m\vec{v}$. Any change in momentum (in either MAGNITUDE and/or direction) over TIME (t) will be the result of an external influence, forming the impulse: $\vec{J} = \Delta\vec{p} = \int_{t_1}^{t_2} \vec{F} dt$. RENÉ DESCARTES (1596–1650) made the first announcement with respect to conservation of momentum in 1644.

Law of conservation of parity

[atom, nuclear, quantum] Parity is the constraints that apply to a position function, specifically when applying space inversion. When the position function remains unchanged under the transformation the PARITY is considered to be either positive, or even, while if the function changes only in sign (+/–) under the INVERSION from positive to negative coordinates the parity is odd or negative. Other changes are not defined by parity. A system can be described by wave-functions and under conservation of parity there can be no distinction between clockwise and counterclockwise or right and left for any fundamental physical interactions. Elementary, there can be no distinction between a right-handed physical system and a left-handed system.

Law of corresponding states

[energy, fluid dynamics, general, thermodynamics] All gases look and act alike if they initially obey the VAN DER WAALS EQUATION OF STATE when TEMPERATURE (T), PRESSURE (P), and VOLUME (V) are expressed in DIMENSIONLESS quantities ($\hat{\square}$) as $\hat{T} = T/T_c$; $\hat{P} = P/P_c$ and $\hat{V} = V/V_c$, where $\square_c$ defines the Van der Waals conditions at the critical temperature. The constants can be derived from the PT curves. The corresponding states are now defined by $\left[\hat{P} + \left(3/\hat{V}^2\right)\right]\left[\hat{V} - (1/3)\right] = (8/3)\hat{T}$. The LAW OF CORRESPONDING STATES served as a guide to J. Dewar during his experimental efforts in liquefying hydrogen in 1898 and to H. Kamerlingh Onnes leading to the LIQUEFACTION of helium in 1908.

Law of cosines

[computational, general] For a regular triangle the sides (A, B, C) all relate to each other with respect to the ANGLE opposite to the respective ridge (respectively: α, β, γ) are related as $C^2 = A^2 + B^2 - 2AB\cos\gamma$ see PYTHAGORAS).

Law of definite proportions

[computational, general] In any CHEMICAL COMPOUND the respective constituents will always be present in the same proportions independent of the manner in which the aggregate was synthesized. The criteria

resulted from the work performed by ANTOINE-LAURENT DE LAVOISIER (1743–1794). For instance, WATER (H_2O) will always be split into constituents (i.e., ELEMENTS) with 2:1 ratio. The chemical reconstruction was more formally defined by JOHN DALTON (1766–1844) in 1808.

Law of Dulong and Petit

[general, thermodynamics] The raising of the temperature of a specific molecular configuration (i.e., chemical composite) requires a fixed amount of ENERGY that corresponds to the chemical configuration. This means that the SPECIFIC HEAT of a material has a constant value. This EQUIVALENCE PRINCIPLE was experimentally verified and expressed in 1819 by PIERRE LOUIS DULONG (1785–1838) and ALEXIS THÉRÈSE PETIT (1791–1820).

Law of increasing disorder

[general] Generally process that consume ENERGY or produce pollution or will result in an increase in disorder, thereby limiting the validity of the theoretical solution for an idealized process. Additionally, most natural processes are irreversible, they begin from a state of equilibrium which is disturbed by changing boundary conditions, degrading the system, such as a melting ice cube placed in a GLASS of water. The entropy of the frozen water will increase (see SECOND LAW OF THERMODYNAMICS).

Law of inertia

[general, mechanics] Initially proclaimed by GALILEO GALILEI (1564–1642) around 1638, but later formally defined by SIR ISAAC NEWTON (1642–1727) (see NEWTON'S FIRST LAW).

Law of inertia, rotational equivalent

[general] A body is compelled to perform a rotation with fixed angular velocity unless an external torque is applied. (Note: The initial revolution is the result of an applied torque, which may, for instance, be from physical mechanical interaction, electric or MAGNETIC FIELD, or GRAVITATION.)

Law of interaction

[general, mechanics] To every action there is always an opposite and equal reaction; in other words, force acts in pairs, EARTH pushed back with an equal force (i.e., Normal force) as the force resulting from GRAVITATIONAL ACCELERATION exerted on a mass (also NEWTON'S THIRD LAW, SIR ISAAC NEWTON [1642–1727]).

Law of large numbers

[computational] Any phenomenon can be defined by a number (n) of random variable-independent events (Ξ_i), each occurring with a certain associated PROBABILITY ($P(\Xi)$). Letting the number of events become large (not necessarily approach infinity) forces the description to converge within the product of the number of events and the respective mean value (μ_{mean}) with respect to the VARIANCE (σ^2). Expressing the phenomenon as a series (S_n^e) yields $\lim_{n \rightarrow \text{large}} S_n^e/n = (\sum_{i=1}^n \Xi_i) - n\mu_{\text{mean}} \rightarrow 0$.

Law of mass action

[biomedical, thermodynamics] The equilibrium condition for a single chemical reaction, expressed as $\prod_{i=1}^q (P_i/P_0)^{C_i} = \exp -[(1/RT)\sum_{i=1}^q C_i V_{ai}(T, P_0)] = K(T)$, where C_i is the stoichiometric number of the i th constituent of the chemical reaction (defined by $\sum_{i=1}^p C_i \mathcal{A}_i$ (phase), with $\mathcal{A}_i$ (phase) the PHASE conditions for the respective constituents; C_i will be positive for products, negative for reactants, and zero for noncontributing chemical reagents), $V_{ai} = G_i(T, P)$ is the chemical potential for ingredient i (note this equals the Gibbs free ENERGY), P_0 the standard pressure (usually 1 atm), P_i the Partial pressure of the i th component, T is the local temperature, and $R = 8.3144621(75) \text{ J/Kmol}$ the GAS constant, and $K(T)$ is the “equilibrium constant” at specific temperature for the chemical reaction. (Note: $\prod_j^s (\chi)$ is the product operator.) Also referred to as the law of mass action of Guldberg or law of mass action of Guldberg, Waage, van't Hoff, and Horstmann.

Law of Pascal

[fluid dynamics, thermodynamics] When pressure is applied to a confined LIQUID this pressure will extend in all directions with equal MAGNITUDE and equal potential. This principle, for instance, forms the basis for hydraulic lifts, where pressure is translated into force by means of controlling the size of the free-moving surface area. An indirect consequence of this principle is that for a liquid that is in equilibrium under uniform pressure the surface will always assume a horizontal position. Consider the volume of liquids illustrated by figure, where all named points represent segments perpendicular to the surface with unity length. Neglecting the pressure gradient over the height: $h_2 - h_1$ makes the pressure on the surface outlined between the respective edge segments $A_{20} \Leftrightarrow A_{21}$ and $K \Leftrightarrow A_{21}$ uniform. The pressure magnitudes of the respective pressure vectors: $\overline{A_{21}}$ on the surface outlined by edges $A_{20} \Leftrightarrow A_{21}$, $\overline{A_{22}}$ on the surface outlined by $K \Leftrightarrow A_{21}$, and $\overline{A_{23}}$ on the surface outlined by $K \Leftrightarrow A_{20}$ are considered to be in HEART of the respective surfaces and are perpendicular to each surface of the WALL of the reservoir. The vectors intersect in point A_{02} on the wall of the container. Due to the fact of equilibrium (no flow conditions) the pressure triangle (insert 1) is equivalent to the triangle outlined by the respective surfaces, which yields $|\overline{A_{21}}|/\text{Area}(A_{20} \Leftrightarrow A_{21}) = |\overline{A_{22}}|/\text{Area}(K \Leftrightarrow A_{21}) = |\overline{A_{23}}|/\text{Area}(K \Leftrightarrow A_{20})$ meaning the pressure on each surface is equal. The pressure on the respective surface is equal to the product of the surface area times the height of the center of mass of the liquid resting on the center of the surface multiplied by the specific GRAVITY of the liquid.

Law of reflection

[acoustics, general, optics] When an electromagnetic or acoustic beam strikes a reflective surface, or when a ball is thrown at a WALL, the ANGLE of incidence (θ_i) equals the angle of reflection (θ_r); measured in reference with the normal to the surface: $\theta_i = \theta_r$.

Law of refraction

[acoustics, general, optics] A WAVE will travel from one medium ($\square_1$) with respective speed of propagation to another medium ($\square_2$) with a different density (expressed by the ANGLE with respect to the normal θ) and associated speed of propagation and the path of propagation will bend away from the normal to the surface of the second medium when this is more dense and toward the normal when less dense. When exceeding the CRITICAL ANGLE for the incident wave all the WAVE trajectories will be reflected. In OPTICS, the index of REFRACTION represents the optical density, where the speed of propagation (v) is less than for vacuum (c = speed of light): $n = c/v$. The LAW OF REFRACTION for ELECTROMAGNETIC RADIATION is expressed as $n_1 \sin \theta_1 = n_2 \sin \theta_2$. Also referred to as SNELL'S LAW. For ACOUSTICS, this is captured by the acoustic index which is a function of DENSITY (ρ) and ELASTIC MODULUS (E_{el}): $n_{mech} = \sqrt{\rho/E_{el}}$, which can be temperature dependent and hence gradual, however for a single medium this can also be the case in optics (see SNELL'S LAW OF REFRACTION).

Law of similarity

[fluid dynamics] See FROUDE'S LAW OF SIMILARITY.

Law of sines

[computational, general] For a regular triangle the sides (A, B, C) all relate to each other with respect to the ANGLE opposite to the respective ridge (α, β, γ , respectively) are related as $\sin \alpha / A = \sin \beta / B = \sin \gamma / C$.

Law of the constancy of the speed of light

[general] The speed of light in free space has an invariant value for an inertial system. This entails that the speed of light will be independent of the velocity of the source while in MOTION. This is also Einstein's second postulate.

Law of the lever

[general, mechanics] An object that is subjected to zero total torque (τ_F) will be in rotational equilibrium: $\sum \tau_F = \sum F_i r_i = 0$, where F_i represents the individual forces attached to a point at DISTANCE r_i from a pivotal point of reference (see Figure L.52).

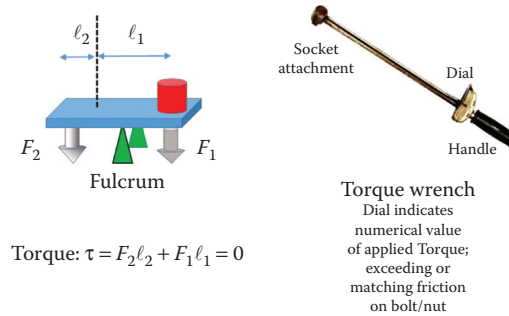


Figure L.52 (a) Law of the lever (b) Dial indicating the torque applied with the lever when attached to a bolt/nut on the top left and a hand pulls up/down on the bottom right; torque applied over the distance separating the two points. Nut will turn when no opposite torque is applied.

Law of universal gravitation

[general] Every object in the UNIVERSE attracts every single other object regardless of size with a MAGNITUDE that is directly proportional to the product of the masses of the two objects (m_1 and m_2 , respectively) while inversely proportional to the square of the DISTANCE separating the two objects (r) with a force F defined as $F = G(m_1 m_2 / r^2)$, where $G = 6.67 \times 10^{-11} \text{ Nm}^2 / \text{kg}^2$ is the universal gravitational constant. (Note: The GRAVITATION attraction of an object with arbitrary shape and uniform density is identical to a point source with the same mass at a matching distance to the CENTER OF GRAVITY of the object outside the object.) The asphericity of EARTH will as such have a different GRAVITATIONAL ACCELERATION as a function of the LATITUDE.

Law of viscosity, Newton

[fluid dynamics] The viscous behavior of liquids described by SIR ISAAC NEWTON (1642–1727) under restricted conditions (i.e., Newtonian liquid) defines that the rate of shear stress ($\tau = F/A$) is directly proportional to the rate of shear strain: $\partial v / \partial y$, where y is the DISTANCE with respect to the object under stress for an object or LIQUID under deformation as a result of an externally applied FORCE (F) on the surface with area A . This Newtonian behavior stand in contrast to shear-thickening fluids/materials, shear-thinning fluids/materials and Bingham plastics, for instance. Note: In reference, the drag-force (F_d)

on a sphere with diameter d falling in a quiescent liquid cylinder with viscosity η_{visc} expressed as $F_d = 6\pi\eta_{\text{visc}}vd$, where v is the velocity of the falling object, this is called the Stoke's law (see Figure L.53).

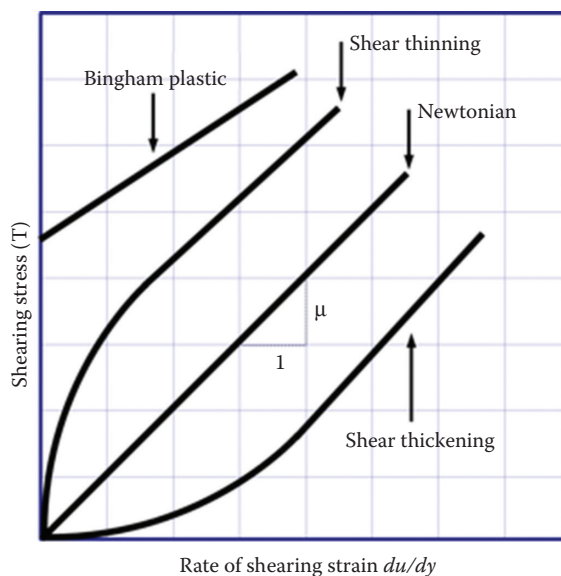


Figure L.53 Newton's law of viscosity.

Lawrence, Ernest Orlando (1901–1958)

[atomic, nuclear] Scientist from the United States. Lawrence's work included the development of the CYCLOTRON used for PARTICLE acceleration (e.g., ALPHA PARTICLE, DEUTERON, and PROTON) and nuclear collision measurements (see Figure L.54).



Figure L.54 Ernest Orlando Lawrence (1901–1958) in 1939.

Lawrence Livermore National Laboratory

[general] Federal research facility in partnership with the University of California, Bechtel, Babcock & Wilcox, URS, the Battelle Memorial Institute as well as Texas A&M University. The facility was founded in 1952 and houses one of the most powerful laser systems, The Nova laser. The principal task is to research on the safety and efficacy of nuclear weaponry (see [Figure L.55](#)).



Figure L.55 Aerial photograph of the Lawrence Livermore National Laboratory. (Courtesy of Michael Macor, *The Chronicle*.)

Laws of engineering and physics (as well as mathematics)

[general] The following laws and principles defining phenomena and actions related to the fields of physics, ENGINEERING, and chemistry are AMPÈRE'S LAW, Ampère's circuital law, AMPÈRE–Maxwell law, ARCHIMEDES PRINCIPLE, associative law, AVOGADRO'S LAW, BAROMETRIC LAW, Beer–Lambert law, BIOT–SAVART LAW, BLANC'S LAW, BOLTZMANN DISTRIBUTION LAW, Bouguer law, BOYLE'S LAW, Bragg's law, BREWSTER'S LAW, BUYS–BALLOT LAW, Carnot principle, CASSINI'S LAWS, CHARLES' LAW, commutative law, CONTINUITY EQUATION, COULOMB LAW, CURIE LAW, degenerate gas LAW, distributive law, DULONG–PETIT LAW, FARADAY LAW, FERMAT PRINCIPLE, FIRST LAW OF THERMODYNAMICS, Fick's law, FIRST POSTULATE OF RELATIVITY, FOURIER'S CONDUCTION LAW, FROUDE'S LAW OF SIMILARITY, GAUSS'S LAW, Gay–Lussac law, GRAHAM'S LAW OF DIFFUSION, GREEN'S LAW, GUTENBERG–RICHTER LAW, HAGEN–POISEUILLE LAW, HENRY'S LAW, HOOKE'S LAW, HUBBLE'S LAW, HUND'S LAW, HUYGENS' PRINCIPLE, JOULE'S LAW, KEPLER'S LAWS, KIRCHHOFF LAWS, KIRCHHOFF'S RADIATION LAW, KIRCHHOFF'S LOOP RULE, KIRCHHOFF'S NODE RULE, LE CHÂTELIER–BRAUN PRINCIPLE, LAPLACE LAW, LAPORTE RULE, LAW OF ANGULAR MOMENTUM, LAW OF CONSERVATION OF ANGULAR MOMENTUM, law of conservation of atomic nuclei, LAW OF CONSERVATION OF CHARGE, law of conservation of electric current, LAW OF CONSERVATION OF ENERGY, law of CONSERVATION OF LINEAR MOMENTUM, law of CONSERVATION OF MASS, law of CONSERVATION OF MASS–ENERGY, LAW OF CONSERVATION OF MECHANICAL ENERGY, LAW OF CONSERVATION OF MOMENTUM, LAW OF CONSERVATION OF PARITY, LAW OF CORRESPONDING STATES, LAW OF COSINES, LAW OF DEFINITE PROPORTIONS,

LAW OF DULONG AND PETIT, LAW OF INCREASING DISORDER, LAW OF INERTIA, LAW OF INTERACTION, LAW OF LARGE NUMBERS, LAW OF MASS ACTION, LAW OF MASS ACTION OF GULDBERG–WAAGE–VAN’T HOFF AND HORSTMANN, LAW OF PASCAL, LAW OF REFLECTION (SNELL), LAW OF REFRACTION (SNELL), LAW OF SIMILARITY, LAW OF SINES, LAW OF THE CONSTANCY OF SPEED OF LIGHT, LAW OF THE LEVER, LAW OF MASS ACTION, LAW OF UNIVERSAL GRAVITATION (NEWTON), LAW OF VISCOSITY (NEWTON), laws of motion, LAWS OF PLANETARY MOTION, LAWS OF THERMODYNAMICS, LENZ’S LAW, LORENTZ FORCE LAW, MOORE’S LAW, MALUS’S LAW, MAXWELL EQUATIONS, MOSELEY’S LAW, MURRAY’S LAW, NEWTON’S FIRST LAW, NEWTON’S SECOND LAW, NEWTON’S THIRD LAW, NEWTON’S LAW FOR FLUIDS, NEWTON’S LAW OF COOLING, OHM’S LAW, PASCHEN LAW, PERIODIC LAW, RADIOACTIVE DECAY LAW, RAOULT’S LAW, SECOND LAW OF THERMODYNAMICS, second postulate of relativity, SNELL’S LAW, STARLING’S LAW, Stefan’s law, STOKE’S LAW, superposition principle, TATE’S LAW, Torricelli’s law, VAN’T HOFF LAW, AND WORK–ENERGY THEOREM.

Laws of planetary motion

[astrophysics, mechanics] There are THREE LAWS OF PLANETARY MOTION, all derived by JOHANNES KEPLER (1571–1630). KEPLER’S FIRST LAW states that all planets in our SOLAR SYSTEM revolve around the Sun in an elliptical orbit. KEPLER’S SECOND LAW relates to the speed of MOTION with respect to the segment of the orbit. Each line drawn from the Sun to a PLANET will mark off equal areas in the orbital plane for equal time intervals. KEPLER’S THIRD LAW correlates the average Sun-to-planet DISTANCE (r_0 , denoting the Sun as the central body) to the period of revolution (T) as a constant: $r_0^3/T^2 = C_\odot = 1 \text{ Astronomical unit}^3/\text{Earthyear}^2$, where Astronomical unit = $1.5 \times 10^{11} \text{ m}$ and Earthyear = $31.6 \times 10^6 \text{ s}$ the time it takes for the EARTH to circumvent the Sun (365.24 days) (*see* JOHANNES KEPLER [1572–1630]).

Laws of thermodynamics

[biomedical, energy, general, nuclear, solid-state, thermodynamics] There are three laws of thermodynamics, zeroth, first, and second. The ZEROTH LAW OF THERMODYNAMICS was introduced by JOSEPH BLACK (1728–1799) around 1760. The FIRST LAW OF THERMODYNAMICS was introduced in 1850 by RUDOLF JULIUS EMANUEL CLAUSIUS (1822–1888) and WILLIAM RANKINE (1820–1872). The SECOND LAW OF THERMODYNAMICS was introduced based on the concepts introduced by Rudolf Clausius in 1854, LORD KELVIN (1824–1907) in 1851, and the axiomatic thermodynamics statements from CONSTANTIN CARATHÉODORY (1873–1950) in 1909.

Lay

[biomedical, mechanics] Indication of SURFACE ROUGHNESS. Specifically, the deviation from the established and defined “normal” shape and geometry as created by milling and machining. The “Lay” describes

the general direction of a surface treatment resulting from the methods used. Lay can be circular, cross-hatch, multidirectional, parallel, particulate, perpendicular, and radial (see [Figure L.56](#)).

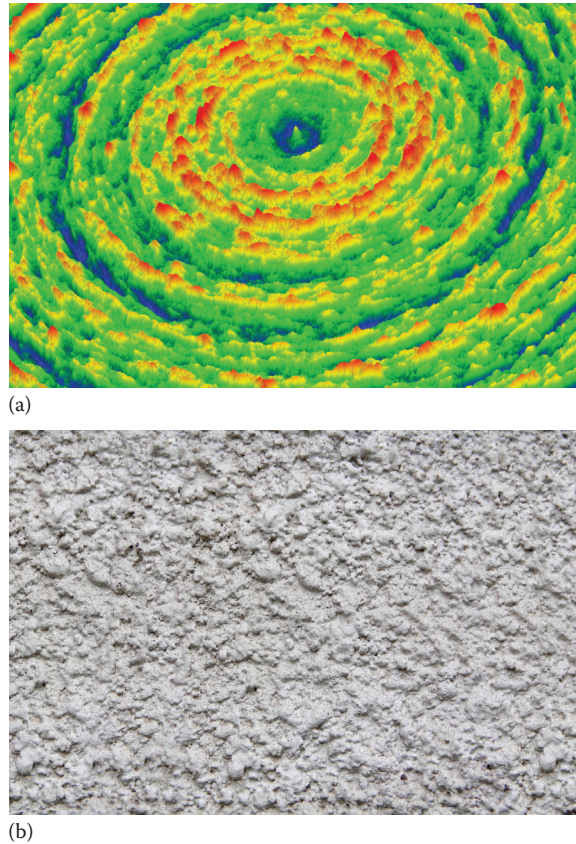


Figure L.56 (a) Microscopic image portraying a diamond turned surface finish measurement (Courtesy of Zygo.) and (b) surface roughness. (Surface standard ANSI B46.1-1962 implemented by the American Society of Mechanical Engineers.).

L-C-R AC network

[electronics, general] Circuit containing an INDUCTOR (L), CAPACITOR (C), and RESISTOR (R), and the way an alternating signal (AC) propagates through according to the “cable equation” (also referred to as the WAVE EQUATION or the TELEGRAPH EQUATION). The circuit may be arranged in parallel and series connections in various combinations. Specifically, the circuit can be designed as a frequency filter, SIGNAL integrator (i.e., “average”), or amplifier. The telegraph equation (derived its name from the early days of wired analog data transmission) is used to derive the electrical potential (U_{pot}), which varies with time, as a function of

the propagation path length ($d\zeta$) as a function of TIME (t) as can be found by solving a one-dimensional differential equation: $(1/LC)(d^2U_{\text{pot}}/d\zeta^2) = (d^2U_{\text{pot}}/dt^2) + [(R/L) + (\mathbb{R}/C)](dU_{\text{pot}}/dt) + (\mathbb{R}R/LC)U_{\text{pot}}$, where $\mathbb{R}$ represents the conductivity over a length of schematic (see Figure L.57).

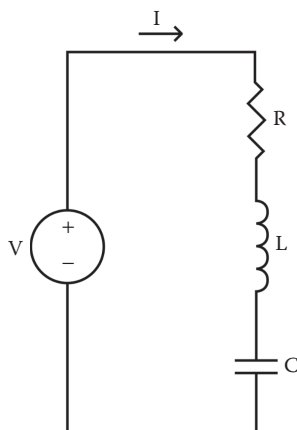


Figure L.57 Representation of the manner in which an alternating signal (AC) interacts with an L-C-R network, circuit containing an inductor (L), capacitor (C), and resistor (R).

Le Châtelier, Henry Louis (1850–1936)

[chemical, thermodynamics] Chemist from France. Henry Le Châtelier is most known for the definition of the boundary conditions of a chemical reaction, and their influence on its process (*also see* CHÂTELIER–BRAUN PRINCIPLE) (see Figure L.58).



Figure L.58 Henry Louis Le Châtelier (1850–1936).

Le Châtelier–Braun inequalities

[chemical, thermodynamics] ENERGY constraints for potential energy (or internal energy: U_{pot}) as well as VOLUME (V) as a function of temperature (T , in this case $1/T$) for a number of reagent constituents (n) under certain PRESSURE (P) of a system with entropy (S tied to the Gibbs free energy ($G = U - TS + PV$)) defined as $[\partial(1/T)/\partial U]_{V,n} \leq [\partial(1/T)/\partial U]_{P/T,n} < 0$ and $[\partial(P/T)/\partial V]_{U,n} \leq [\partial(P/T)/\partial V]_{1/T,n} < 0$. These expressions entail the following; with increasing energy the PROBABILITY for energy release is increasing,

equivalently an increase in volume will promote the surrender of volume (hence contradicting the increase: $d(P/T) < 0$). This inequality can be rewritten using the link between entropy and internal energy as: $[\partial T / \partial S]_{V,n} \geq [\partial T / \partial S]_{P,n} > 0$ and $-[\partial P / \partial V]_{S,n} \geq -[\partial P / \partial V]_{T,n} > 0$.

Le Châtelier–Braun principle

[chemical, thermodynamics] Chemical equilibrium as described independently by both HENRY LOUIS LE CHÂTELIER (1850–1936) and Karl Ferdinand Braun (1850–1918). The principle confines the response of a chemical system to perturbations, hence subduing the rate of progression and enhancing the stability of equilibrium of the system. The mechanism of action can be traced from the LE CHÂTELIER–BRAUN INEQUALITIES. With respect to a chemical reaction this translates into the fact that when the concentration of one constituent ($[\chi]$) changes the chemical reaction will shift in the direction to counteract this particular change: $a[A] + b[B] \rightleftharpoons c[C] + d[D]$ (also Le Châtelier principle; *also see* HOMEOSTASIS).

Le Verrier, Urbain (1811–1877)

[astronomy, mechanics] Scientist and mathematician from France, known for his discovery of the PLANET Neptune (see [Figure L.59](#)).



Figure L.59 Urbain le Verrier (1811–1877).

Lead storage cell

[general] Charge storage device using lead oxide (PbO_2) and ACID (e.g., sulfuric acid: H_2SO_4) that can release the stored electrical charge as a current under a fixed potential, generally at 2V per CELL. The lead storage cell is commonly used in automobiles and is rechargeable. The lead storage cell or lead-acid BATTERY was invented

by the French physicist Gaston Planté (1834–1889) in 1859. The chemical exchange supporting the ELECTRON (e^-) current is as follows: on the negative (CATHODE) side $Pb + HSO_4^- \rightarrow PbSO_4 + H^+ + e^-$ and on the anode $PbSO_2 + HSO_4^- + 3H^+ + 2e^- \rightarrow PbHSO_4 + 2H_2O$. The current MAGNITUDE can theoretically be derived from the molecular weights of the constituents in the chemical reaction, which equals 642.6. A BATTERY with a mass of 642.6 g of reagent material can theoretically produce 2 Faraday of electrical charge, which equates to 84.3 AmpH per kilogram, where 1 Ampere – Hour = 3600 Coulomb (see [Figure L.60](#)).

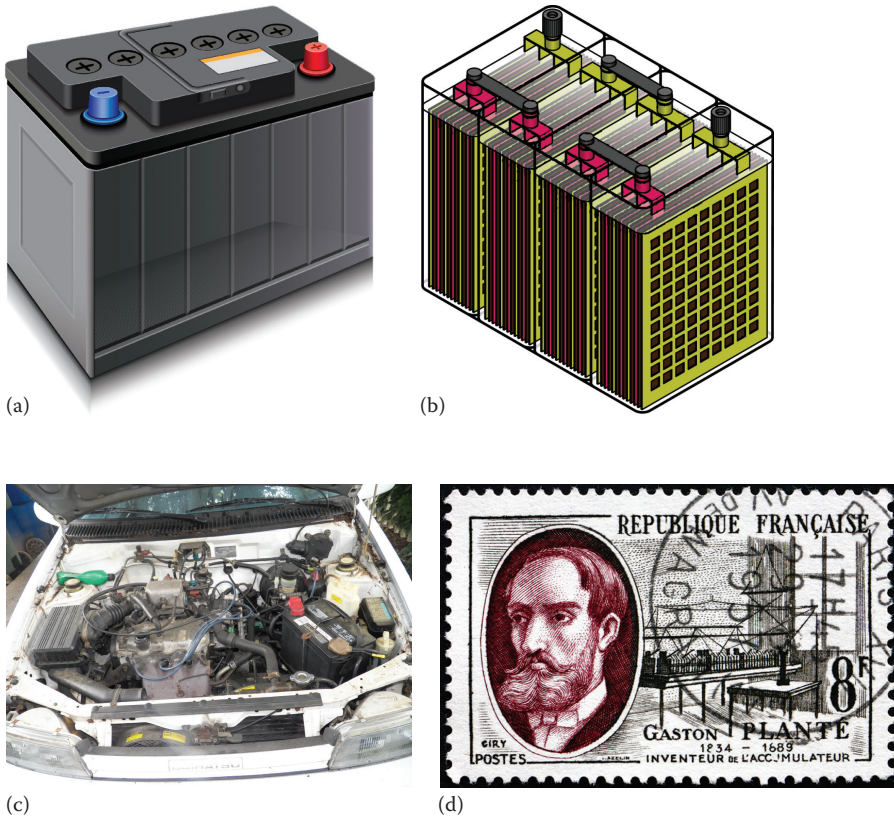


Figure L.60 (a) Outside view of lead-acid battery, (b) diagram of lead plate-configuration in lead-acid battery, (c) lead-acid battery in engine compartment of automobile, and (d) Image of Gaston Planté (1834–1889) from France, the inventor of the lead-acid battery.

Lead zirconate titanate (PZT)

[acoustics, biomedical, mechanics] Ceramic medium that can convert electrical ENERGY into MECHANICAL ENERGY and vise-versa. When applying a zeroth order sinusoidal alternating current to PZT the material will perform a single frequency OSCILLATION at the same rate as the current. This principle is for instance applied in ULTRASONIC IMAGING and FLUID pumps. The generated FREQUENCY (v_z) is a function of the crystal dimension in the direction of wave propagation (z), a material properties resulting from the manufacturing mechanism (k_z^v) known as the “frequency constant,” at a specific harmonic (n) of RESONANCE: $v_z = n(k_z^v/z)$. The reverse is applied in STRAIN-GAUGES, measuring contraction and EXPANSION rate of

change and MAGNITUDE. PZT is one of the most well-known and oldest materials in this application, however many new materials are developed on an ongoing basis (see [Figure L.61](#)).

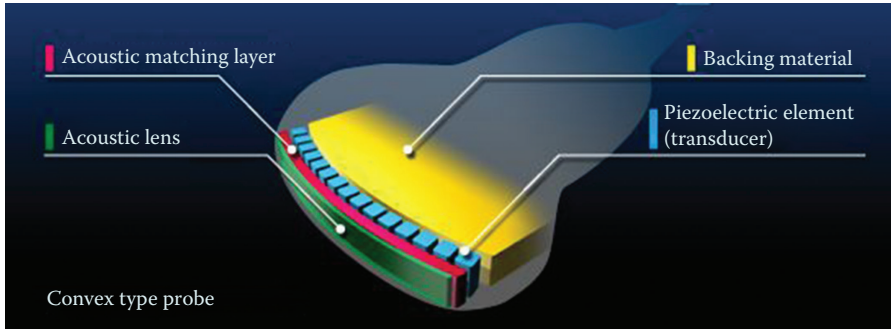


Figure L.61 Image of linear-array lead zirconate titanate (PZT; element lead = Latin *plumbum* [Pb]) ultrasound probe. (Courtesy of Epoxy Set Inc., Lincoln, Rhode Island.)

Leading edge

[fluid dynamics] BOUNDARY LAYER in FLOW that evolves from a point-of-contact: the leading edge, may also be referred to as the point of inception.

Leapfrog method

[computational] Technique used in NUMERICAL methods. In finite ELEMENT or finite step calculations, the values for a specific function are derived through a process where the function is calculated at one point that is relatively easy, the next data point is calculated after a leap over the coordinates to provide the next mid-step values, while the value at the “leapfrog” coordinate can be found through interpolation.

Least squares

[computational] Process used in data fitting, to closely match a well-defined function to a nonconformal range of data with respect to experimental observations. Usually the system is overdetermined and needs to be scaled down for conclusions. The least-squares mechanism can be attributed to the German mathematician CARL FRIEDRICH GAUSS (1777–1855), used in 1795, however, the method may very well have been published prior to this by the French mathematician ADRIEN-MARIE LEGENDRE (1752–1833). The mechanism uses the RESIDUALS (R_i) for a series of data points (ζ_i , i.e., dependent variables) at independent values χ_i providing: $R_i = \zeta_i - f(\chi_i, \zeta)$, where $f(\chi_i, \zeta)$ is an approximation or model function that is supposedly a close match, and next minimizes the sum for “smoothing” as described by $\text{Sum} = \sum_{i=1}^{\infty} R_i^2$. Choosing the best fitting function will yield the lowest value for the least-squares. Least square fitting has applications ranging from curve fitting to LINEAR REGRESSION, and is widely used in SIGNAL processing and general statistical methods.

Leclanché, Georges (1839–1882)

[general] Electrical engineer from France. Leclanché invented the first electrical storage device (i.e., the **BATTERY**), known as the Leclanché **CELL** (1866), which evolved into the battery we now know as the alkaline cell (see [Figure L.62](#)).

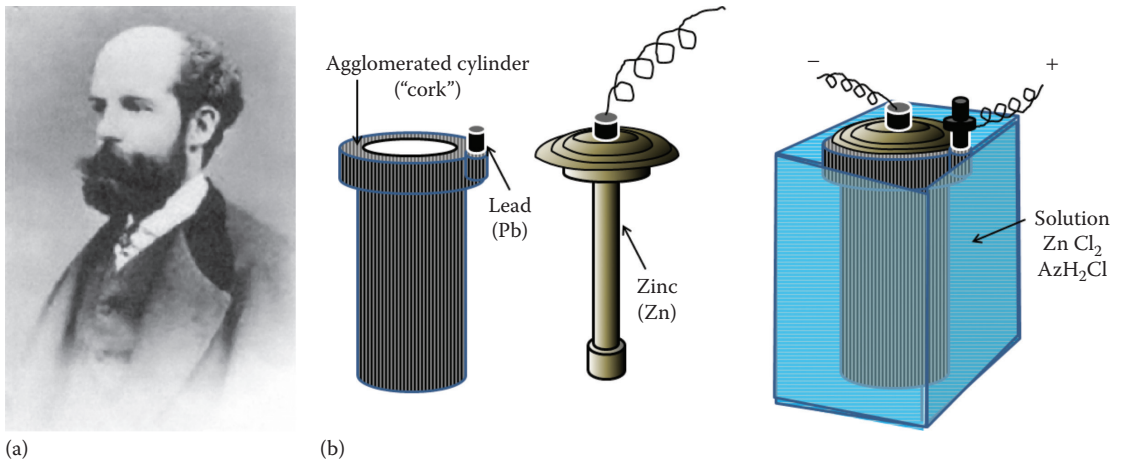


Figure L.62 (a) Georges Leclanché (1839–1882), and (b) Élément Leclanché-Barbier, the first concept of an electric storage device, later evolved into the widely used alkaline cell.

Left ventricular assist device (LVAD)

[biomedical, fluid dynamics] Mechanical pump that is implanted in a patient with reduced **HEART** muscle contraction, and hence reduced **BLOOD** volume stroke. The LVAD is usually installed as a **SHUNT**, bypassing the left ventricle connecting the pulmonary **VEIN** directly with the **AORTA**. Note that the work (W) of the **PUMP** is generally matched to the work of the heart as $W = PV$, where P is the applied pressure or pressure gradient over the system (i.e., device), and V the stroke volume. In case the parallel system does not have equal **FLOW**, there will be backflow through one of the branches with reduced efficacy (see [Figure L.63](#)).

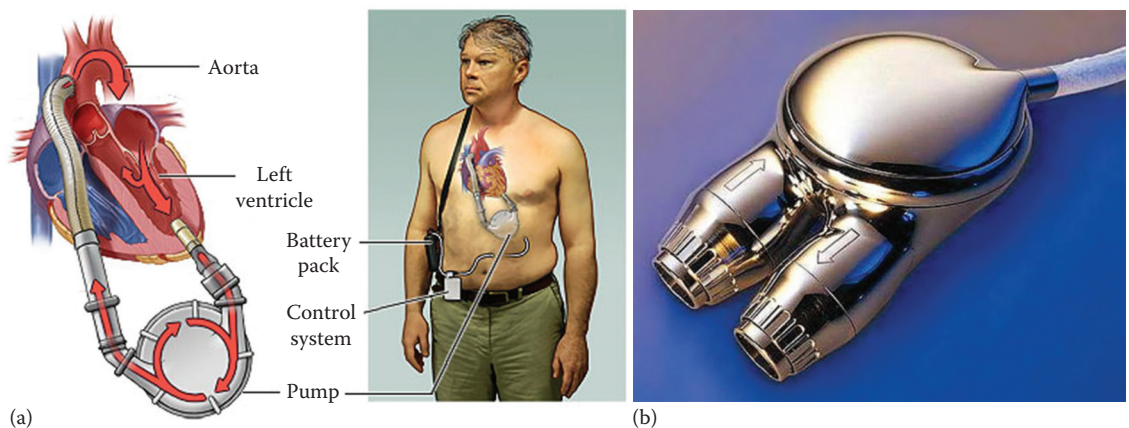


Figure L.63 (a) Left ventricular assist device (LVAD) connected to the heart of a patient. (Courtesy of Healthwise/Thoratec.) (b) Left ventricular assist device (LVAD). (Courtesy of Thoratec.)

Left ventricular pressure

[biomedical, fluid dynamics] The pressure exerted by the left ventricle of the mammalian HEART, pumping BLOOD into the AORTA, crossing the mitral VALVE. The pressure range from diastolic (relaxed) to systolic during full compression. The left ventricular DIASTOLIC PRESSURE will be approximating zero since there is no COMPLIANCE in the system (during the ventricular filling stage the pressure technically turns negative during the EXPANSION phase), compared to the arterial pressure in the arm which has a wind kessel back-up system of the entire vasculature and hence ranges approximately from 30 mm Hg to 160 mm Hg for human SPHYGMOMANOMETER recordings, depending on the personal cardiac and vascular health. The SYSTOLIC PRESSURE will vary with health and exercise history (see Figure L.64).

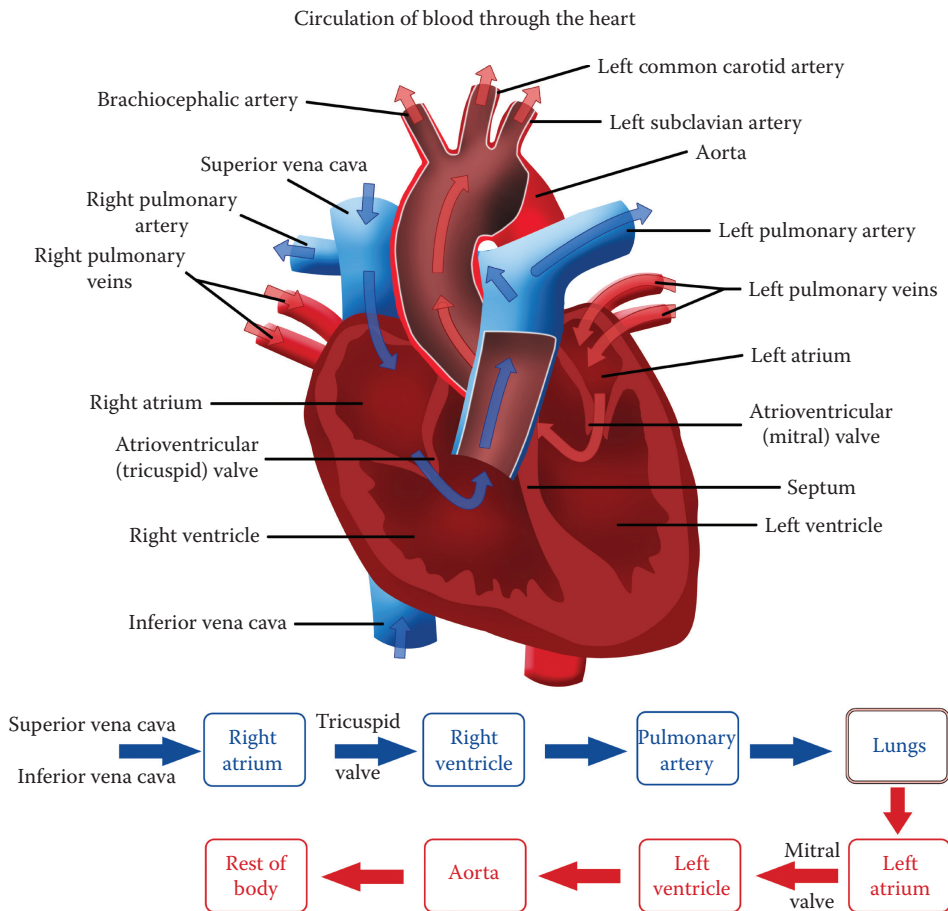


Figure L.64 Left ventricular pressure.

Leg

[biomedical] Anatomical appendage used to provide the mechanism for equilibrium support and translation of a larger biological unit. The leg has a support structure (in mammals consisting of bones) and a

MUSCLE structure to apply a torque, resulting in a pivotal action around a joint. Usually found in even numbers (see [Figure L.65](#)).

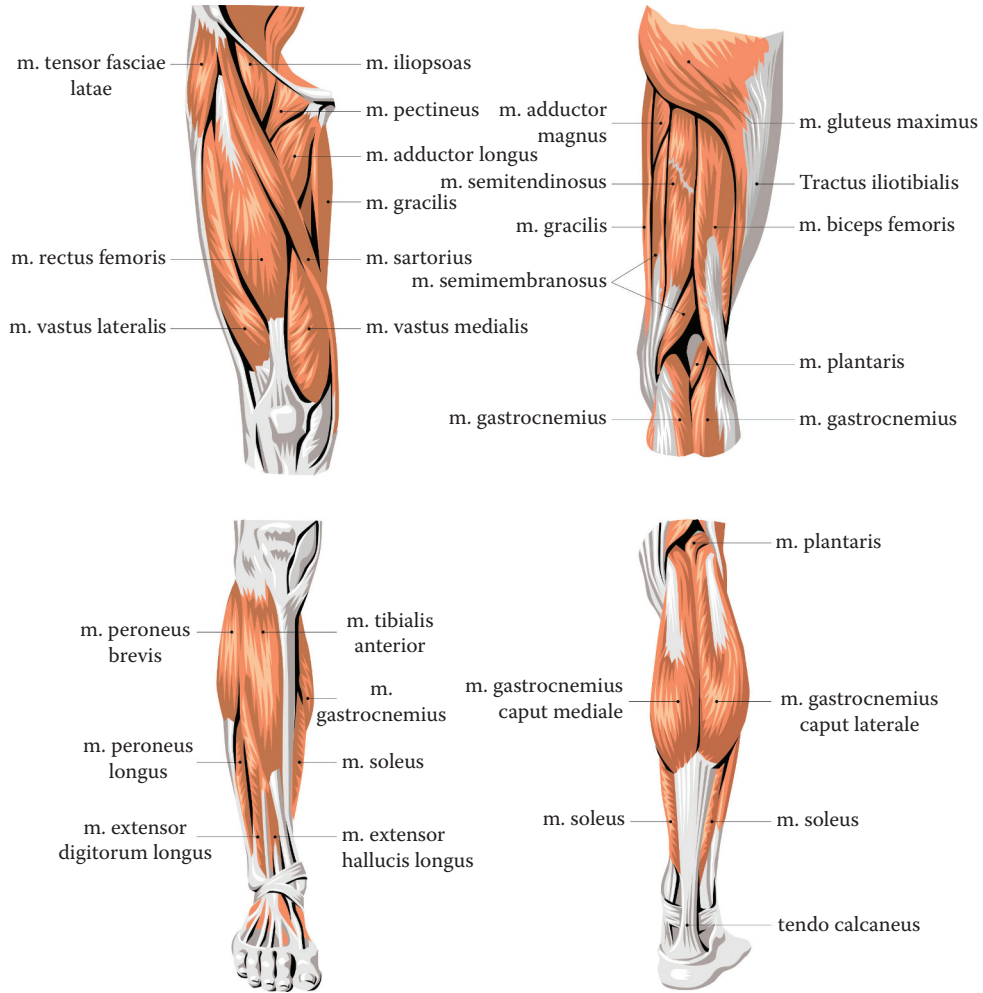


Figure L.65 Representation of the human leg with muscle structure, bone structure, and tendons.

Legendre, Adrien-Marie (1752–1833)

[computational] Mathematician and physicist from France. Legendre is known for his integral transformation as well as polynomial series development of complex functions. The LEGENDRE TRANSFORM is used to solve thermodynamic equations and specifically yield solutions for “enthalpy” and the Gibbs free ENERGY. Legendre also introduced the concept of the LEAST SQUARES method (see [Figure L.66](#)).

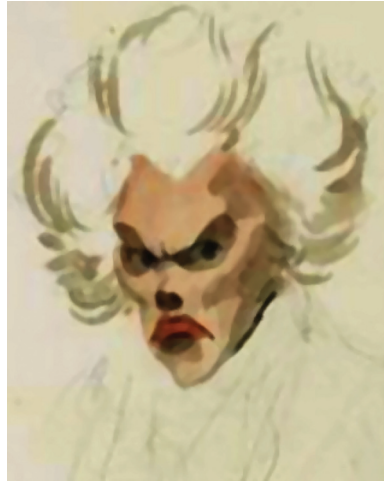


Figure L.66 Adrien-Marie Legendre (1752–1833), watercolor caricature produced in 1820 by French artist Julien-Leopold Boilly.

Legendre differential equation

[astrophysics/astronomy, computational, quantum] Formulation of an expression devised by ADRIEN-MARIE LEGENDRE (1752–1833) to allow complex equations to be solved by approximation: $d/d\chi \left\{ (1-\chi^2) (d/d\chi) P_\ell(\chi) \right\} + \ell(\ell+1) P_\ell(\chi) = 0$, taken in arbitrary direction χ , with the reference frame in spherical coordinates, with as SOLUTION the LEGENDRE POLYNOMIAL power series of orthogonal functions.

Legendre equation

[computational] Basic quadratic equation in three dimensions expressed as $ax^2 + by^2 + cz^2 = 0$ in CARTESIAN COORDINATES, which can only be solved is the following products of the coefficients a, b , and c are quadratic residues: $-ab$; $-bc$; and $-ca$.

Legendre function

[computational] This may refer to the LEGENDRE POLYNOMIAL or the LEGENDRE DIFFERENTIAL EQUATION. Generally, this indicates the solutions to the Legendre differential equation, also known as the Legendre polynomials.

Legendre polynomial

[astrophysics/astronomy, computational, nuclear, quantum] The work of ADRIEN-MARIE LEGENDRE (1752–1833) on celestial MECHANICS resulted in series of polynomials that are of general use. A formal description of a phenomenon may be expanded in the DEGREES OF FREEDOM that can be solved independent from each other. The Legendre polynomials solutions are defined as $P_\ell(\chi) = (1/2^\ell) \sum_{k=0}^{\ell} \binom{\ell}{k}^2 (\chi-1)^{\ell-k} (\chi+1)^k$, which is a SOLUTION to the Legendre differential equation. The Legendre polynomials are azimuthally symmetric. In quantum PHYSICS the WAVE function (Ψ) may be expanded in the respective coordinate systems, specifically in spherical coordinates (r, θ, ϕ) and spherical functions: $\Psi = R(r)\Theta(\theta)\Phi(\phi)$. The polynomials are expressed as follows: $\Theta(\theta) = \sum P_\ell(\cos \theta)$ and $\Phi(\phi) = e^{im\phi}$, where $P_\ell(\cos \theta)$ is a polynomial series of ascending powers of trigonometry functions (the NUMERICAL cut-off on the series development {limit ℓ } will introduce an error which will

set the accuracy of the approximation, primarily based on the boundary conditions), and ℓ and m are integers (e.g., quantum numbers) under the condition $|m| \leq \ell$. In QUANTUM physics the polynomial series is linked to the TOTAL ANGULAR MOMENTUM $M = \sqrt{\ell(\ell+1)}\hbar$, and the angular component with respect to the axis of rotation ($\hat{z}$) as $M_z = m\hbar$, where $\hbar = h/2\pi$, with PLANCK'S CONSTANT: $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$. Another example of the use of Legendre polynomials is in the section on radiative transfer.

Legendre transform

[atomic, computational] Theoretical algorithm used in function approximations, converting a line as a function of location (x), generally expressed as $y = \alpha x + \beta$ to the location of intercept with the vertical axis (β) where $\alpha = dy/dx$ is the slope of the line. When the line is curved the following approximation can be made: $y = \alpha(x)x + \beta(x)$, which converts into $\beta(\alpha) = y(x) - [dy(x)/dx]x$, where $\beta(x)$ is the Legendre transformation of y . This process can be expanded for a range of variables ($\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n$) to yield: $\beta(\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n) = Y(x_1, x_2, x_3, \dots, x_n) - \sum_i [dy(x)/dx_i]x_i$, which transforms the function Y into a series constituted from the slopes of the function at the respective points x_i .

Lehmann, Inge (1888–1993)

[geophysics] Scientist from Denmark who discovered the Earth's inner core in 1929, further explained in separation into an inner and outer core in 1936. The description of the core outline was based on her collection of the velocity of propagation, with subsequent calculation, all based on EARTHQUAKE recording from a multitude of location on the PLANET, in the early 1900s (without the availability of computers). The seismic P-WAVE (compression wave) can travel through LIQUID media (outer core, and layers of the ASTHENOSPHERE), whereas the S-wave (shear wave) cannot. The seismologic work and theoretical description of P-wave propagation offered the essential tools for the modern day monitoring tool for underground (clandestine) atomic detonations (see [Figure L.67](#)).



Figure L.67 Inge Lehmann (1888–1993). (Courtesy of B.A. Bolt.)

Leibniz, Gottfried Wilhelm von (1646–1716)

[general] Mathematician and scientist from Germany, then Electorate of Saxony, Holy Roman Empire. Leibniz is known for the introduction of the integral symbol and principles in mathematical description, as well as the concept of differentiation. He also designed the concept of the binary arithmetic system in 1679. Leibniz is often also considered to be the father of the calculus system in scientific approach and engineering (see [Figure L.68](#)).



Figure L.68 Gottfried Wilhelm von Leibniz (1646–1716).

Leidenfrost, Johann Gottlob (1715–1794)

[general, thermodynamics] Physician from what is now known as Germany. Known for the formal description of a vapor BARRIER between a LIQUID drop and a hot plate, the LEIDENFROST EFFECT (see [Figure L.69](#)).



Figure L.69 Johan Gottlob Leidenfrost (1715–1794).

Leidenfrost effect

[thermodynamics] When a drop of LIQUID is introduced on a hot surface, when the HEAT TRANSFER is high enough, will vaporize the point of contact to form a low-friction BOUNDARY LAYER. The VAPOR barrier simultaneously prevents an effective transfer of heat, leaving the liquid drop virtually intact for an extended period of time. This phenomenon was described by JOHANN GOTTLÖB LEIDENFROST (1715–1794), a German physician (see [Figure L.70](#)).

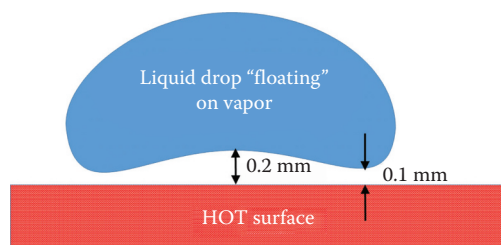


Figure L.70 Illustration of the concept of the Leidenfrost effect, a drop of water appears to “float” above a hot plate.

Lemaître, Monseigneur Georges Henri Joseph Édouard (1894–1966)

[astrophysics/astronomy, atomic, nuclear] Physicist from Belgium, he was also an ordained priest. In 1927 the work of Lemaître was published and revealed what is now known as the Hubble constant. Lemaître was one of the first known people to publish his theory of the EXPANDING UNIVERSE, in this view he proposed the origin of the UNIVERSE, now known as the “BIG BANG THEORY” based on his hypothesis of the “primordial atom.” His theory of the expanding universe is often presented as HUBBLE’S LAW. His doctoral studies were performed under CHARLES DE LA VALLÉE-POUSSIN (1866–1962). The work of ALEXANDER FRIEDMANN (1888–1925) is often taken in association with that of Lemaître. Prior to this the general opinion was that the universe is static, specifically pertaining to the SPECIAL THEORY OF RELATIVITY introduced by ALBERT EINSTEIN (1879–1955) introduced in 1905 (see [Figure L.71](#)).



Figure L.71 Monseigneur Georges Henri Joseph Édouard Lemaître (1894–1966) in 1933, taken while teaching at the Catholic University Leuven, Belgium. (Courtesy of Katholieke Universiteit Leuven/Université Catholique de Louvain, Leuven, Belgium.)

Lenard, Philipp Eduard Anton von

[atomic, nuclear] Scientist from Slovakia, now Germany (*see* VON LENARD).

Length, chord

[fluid dynamics, general, geometry, mechanics] The length of a traced curved path or one-dimensional extend of a real or virtual curved surface (e.g., wing surface in direction of flow) (*see* CHORD).

Length, measurement

[general] France was the first country to commit to a unified system of measures in 1799, using a decimal system, steps/divisions of 10^n , with n = integer, under guidance of emperor Napoleon Bonaparte (1769–1821). The meter as unit of length, was defined as one ten-millionth of the DISTANCE from the at that time accepted location of the North Pole to the equator over the meridian running through Paris, France. Later this was made into a standard that could be used to verify and validate on a universal scale by defining the distance on alloy bar made from platinum and iridium in 1889. Later calibration standards include the definition implemented in 1960 based upon a wavelength of krypton-86 radiation, and the currently (introduction: 1983) accepted distance traveled by light in VACUUM during a time frame of $1/299792458$ s. Length can be measured optically by INTERFEROMETER techniques as well as acoustically based on time of flight, and the old stand-by ruler/tape measure, where the later has a high tolerance due to inherent FATIGUE and wear.

Length contraction

[general] An object observed by an eyewitness that holds the object will have a specific length (L_s). When observed from a DISTANCE when traveling parallel to the object while in MOTION with velocity v will make the object appear shorter (L_m) according to the following rule: $L_m = L_s \sqrt{1 - (v^2/c^2)}$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light with respect to the observation (*see* Figure L.72).



Figure L.72 Graphical representation of the relativistic concept of length contraction.

Lennard-Jones, John Edward, Sir (1894–1954)

[chemical, computational, electronics] Mathematician and scientist from Great Britain. Lennard-Jones dedicated his work to the understanding of the molecular structure and in particular the role of the VALENCE electron (see [Figure L.73](#)).



Figure L.73 Sir John Edward Lennard-Jones (1894–1954).

Lennard-Jones potential

[chemical, computational, electronics, quantum] Molecules and atoms that are not part of a chemical structure (i.e., using the exchange of VALENCE electrons) exert a force on each other that is repulsive at short DISTANCE and attractive at large distance. The electrical POTENTIAL (V) for the “internuclear” spacing between molecules (r_{inter}) expressed as $V(r_{\text{inter}}) = 4U_{\epsilon} \left[\left(r_{\sigma}/r_{\text{inter}} \right)^{12} - \left(r_{\sigma}/r_{\text{inter}} \right)^6 \right]$, where r_{σ} is the intermolecular distance where the potential is zero and U_{ϵ} the ENERGY in the interatomic attraction (i.e., depth of POTENTIAL WELL). The interatomic/intermolecular energy may depend on DIPOLE and quadruple interaction, but on a larger scale this is attributed to transient electric fields that overlap, even at greater distances. The attractive forces may include Van der Waals forces and London forces, but these do not account for the repulsion between molecules at close separation. The repelling mechanism of action may be attributed to collisions. In the SIR JOHN EDWARD LENNARD-JONES (1894–1954) approach, molecules reach a point where they can be considered as “solid” spheres, resulting from the tight electron configuration of the

chemical bounds within the MOLECULE. This principle was considered to offer an explanation for incompressible liquids in the early 1900s (see [Figure L.74](#)).

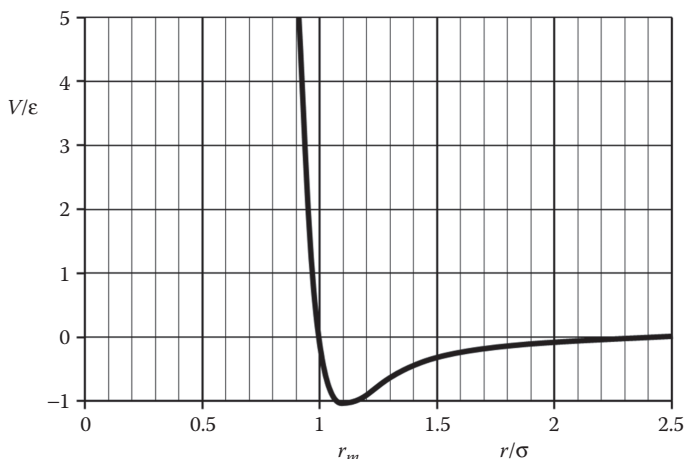


Figure L.74 Graphical representation of the strength of the Lennard-Jones potential with respect to distance.

Lens

[acoustics, biomedical, electromagnetism, general, optics] Device that provides the mechanism of action to change the course of wave-forms: ELECTROMAGNETIC RADIATION, mechanical waves, electric or MAGNETIC fields by themselves, as well as charged particles (technically, also subject to the SCHRÖDINGER WAVE EQUATION). The optical lens mechanism generally falls under GEOMETRICAL OPTICS. Optical imaging with a lens relies on the LAW OF REFRACTION for real or virtual image formation. A set of binoculars or an optical MICROSCOPE uses a set of lenses to form a VIRTUAL IMAGE (as seen by the naked EYE), whereas a CAMERA uses lenses (e.g., zoom lens, fish eye, standard) to project a REAL IMAGE on a PHOTOGRAPHIC PLATE or digital array of CHARGE-COUPLED DEVICE (CCD) elements. Composite lenses can be constructed using various layers of materials, providing physical correction factors for focal length and spectral profiles. Lenses can be symmetric and asymmetric. Examples of asymmetric lenses are cylindrical. The IMAGE forming mechanism (i.e., RESOLUTION) is limited by the diffraction principle defined by the ABBÉ LIMIT, also found as the RAYLEIGH CRITERION. Regular spherical optical lens design can be considered to be carved out by two overlapping spheres, with respective radii, thus forming the basis to the Lens (makers) equation. Spherical lens designs are biconvex, biconcave, planar convex, planar concave, MENISCUS convex, and meniscus concave. Aspherical lens design. In contrast to transmission imaging, mirrors can also form images and have similar design configurations and constraints as well as similar rules apply, but the coordinate system for the image is now reversed. Complex imaging systems use combinations of transmission and reflection, and may also include prisms to shorten the path by means of folding the optical path (e.g., binoculars). In electron beam imaging (TRANSMISSION ELECTRON MICROSCOPE or reflection electron microscope) the electron beam is redirected and collimated to a narrow “focal” point by means of magnetic

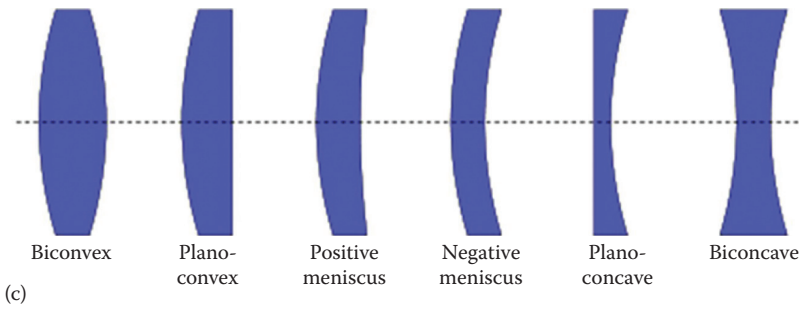
fields. In an electron microscope the lens is a coil or sets of coils arranged in geometric configurations that produces a well-defined MAGNETIC FIELD that can be adjusted (see [Figure L.75](#)).



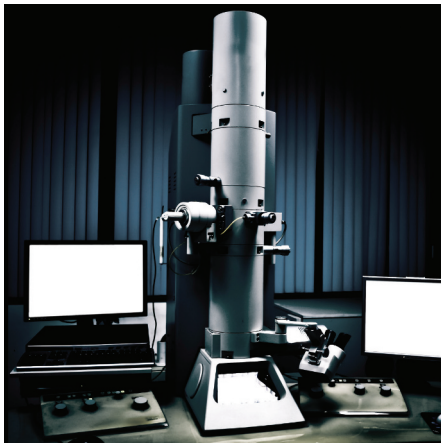
(a)



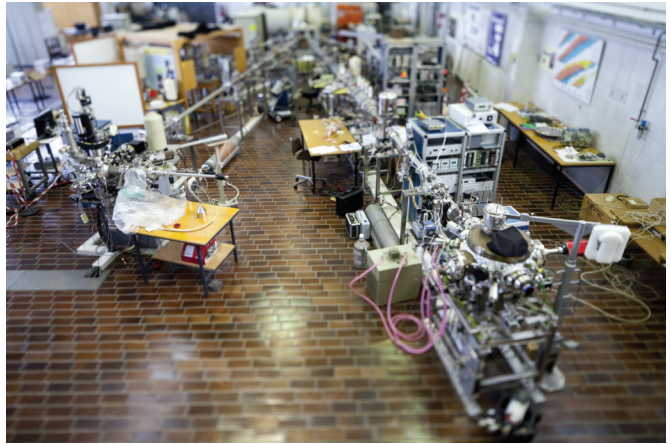
(b)



(c)



(d)



(e)

Figure L.75 Assortment of lens designs and applications: (a) contact lens and lens of the human eye and (b) camera lens cross-sectional view, (c) general concepts in optical lens design, (d) electronic lens for electron microscope, and (e) compound lens design for particle accelerator.

Lens, aspherical surfaces

[general, optics] Lens design that does not use the overlapping sphere configuration. The aspherical lens corrects for material properties and associated aberrations. The EYE is an example of an aspherical lens design (see Figure L.76).

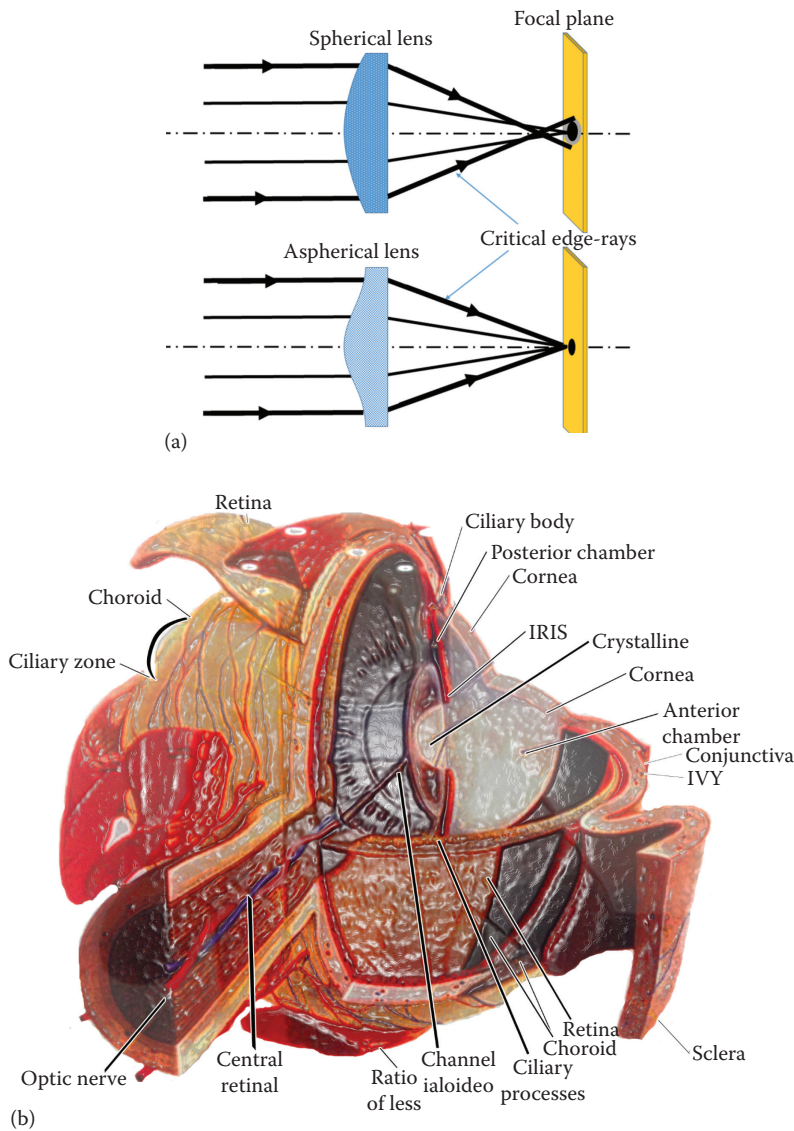


Figure L.76 Aspheric lens design: (a) general design and (b) human crystalline lens.

Lens, Einzel Lens, extended imagery

[general] In charged PARTICLE convergence/divergence with MAGNETIC and electric field LENS design the fields may be contained by hollow disks, CONES or cylinders. In case a hollow cylinder is used that has a set

of two gaps, allowing to form a pair, with TOTAL POTENTIAL difference across the cascading pairs to add to zero is an Einzel lens (see [Figure L.77](#)).

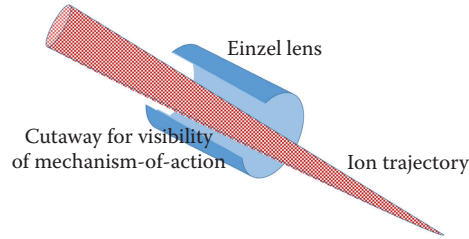


Figure L.77 Einzel lens design for directing charged particles using specific magnetic and electric field configurations.

Lens, focal point and plane

[general] The FOCAL POINT of a LENS will have the rays entering in parallel configuration exit through the focal point. The focal point of the lens is located on the optical axis. The plane perpendicular to the optical axis intersecting in the focal point is the FOCAL PLANE of the lens. Rays passing through a lens from a location that does not intersect with the optical axis will form an IMAGE that does not necessarily coincide with the optical axis, but will fall within the focal plane (see [Figure L.78](#)).

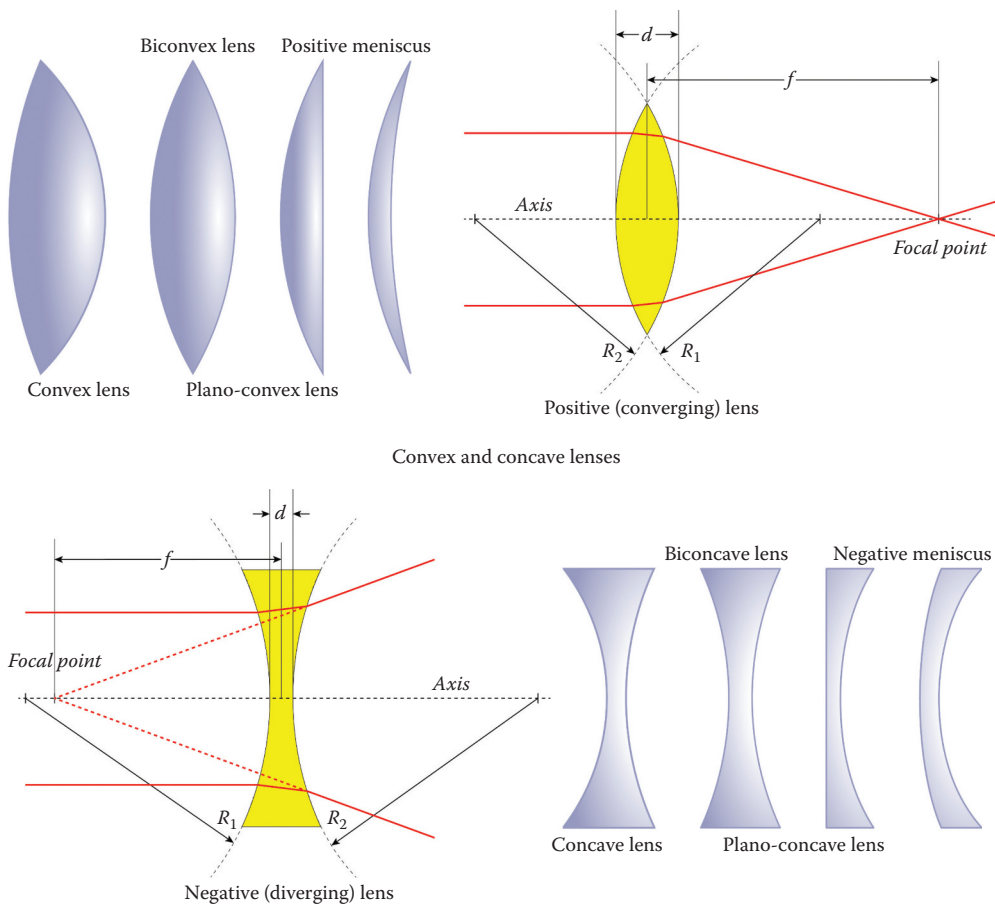


Figure L.78 Focal point and focal plane for a convex and a concave lens design, respectively.

Lens, gravitational

[geophysics] A gravitational LENS describes the influence of a GRAVITATIONAL FIELD on the path of ELECTROMAGNETIC RADIATION. This phenomenon was described by ALBERT EINSTEIN (1879–1955) and was first investigated during a solar eclipse in the year 1919, trying to establish the influence of the sun's own GRAVITATION on the directional emission/propagation of light. The deflection ANGLE (θ_B) induced by a gravitational field with MAGNITUDE proportional to the mass of the object (M) with respect to the incident direction is $\theta_B = 4GM/c^2b$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light, G the gravitational constant, and b an “impact parameter” describing the respective mass influence. This principle may provide the tools to analyze the potential of the phenomenon referred to as “BLACK HOLE.” Images obtained by the HUBBLE SPACE TELESCOPE are prone to gravitational lensing due to the immense distances involved in the field of view for this TELESCOPE (see [Figure L.79](#)).

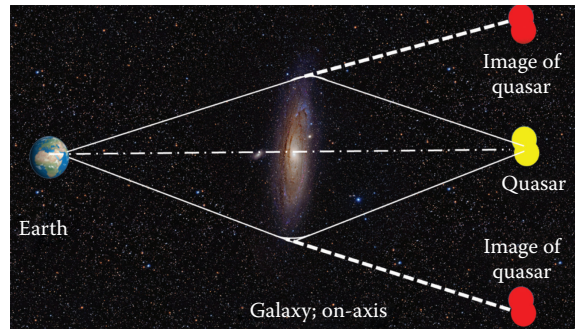


Figure L.79 Diagram of the gravitational lens concept and the practical implications.

Lens, magnetic

[biomedical, general] In charged PARTICLE beam imaging the use of a MAGNETIC multipole (generally quadrupole, in STAR formation with same pole facing each other, opposite POLES adjacent) or discontinuous/asymmetric electric coil. The coil will generate a MAGNETIC FIELD based on the AMPÈRE'S LAW resulting from a current. The magnetic field will interact with the azimuthal component of the velocity of a moving charged particle as well as with the radial component, hence rotating and shifting the IMAGE orientation. One specific example is found in the imaging with positron emission TOMOGRAPHY (see [Figure L.80](#)).

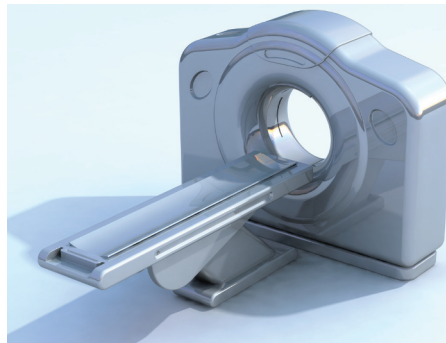


Figure L.80 Illustration of the use of magnetic lenses in the signal collection mechanism of action for a positron emission tomography machine.

Lens, magnification

[general] See MAGNIFICATION.

Lens, thin lens combinations

[general] In order to provide a correction mechanism for the various LENS ABERRATIONS combining more than one lens, each made of material with specific index of REFRACTION and individual focal lengths can provide the means to eliminate the majority of distortions, leaving only border effects to be discarded. Border effects can easily be eliminated by relying on overfill of the recording mechanism (see [Figure L.81](#)).



Figure L.81 Representation of thin lens concept in telephoto lens design for the correction of chromatic and spherical aberrations. The “sandwiched” lenses act as single lenses with a convoluted index of refraction as a function of radius.

Lens aberrations

[acoustics, biomedical, general, optics] Image forming distortions created as a result of the limitations of the LENS or the mechanism of data transfer. Several aberration mechanisms can be recognized: ASTIGMATISM, chromatic, coma, distortion, field-curvature, lateral COLOR. Astigmatism is generally the result of a deformation from symmetry in the lens construction, next to boundary effects in a symmetric lens. In astigmatism tangential lines and radial lines may have an IMAGE that is formed at different locations with respect to the DISTANCE to the lens, thus changing the physical configuration of the image. CHROMATIC ABERRATIONS result from the fact that different colors have different focal points for a lens of a single material (compound lenses can resolve this), thus forming separate image locations for different colors. This results in out-of-focus images of different colors in one single imaging plane. Coma is the distortion where the various zones of a lens form images at different magnification, which result primarily in radial distortions. Distortion is very similar to coma, however the magnification discrepancy is nonuniform, it can be localized due to material imperfections or surface irregularities. Field curvature is similar to astigmatism with the distinction that the image is formed on a concave or convex surface instead of a flat imaging plane, still perpendicular to the optical axis. Lateral color aberration is the phenomenon where the images of respectively different colors are formed at different size in the same imaging plane. Note that an image is considered to be sharply demarcated. The FRESNEL LENS applies a specific form of lens design that intentionally creates an aberration but this is visually interpreted as continuous (discontinuous lens design

based on this principle is for instance the automobile head-light). The Fresnel lens is generally symmetric and is found in light-houses (see [Figure L.82](#)).

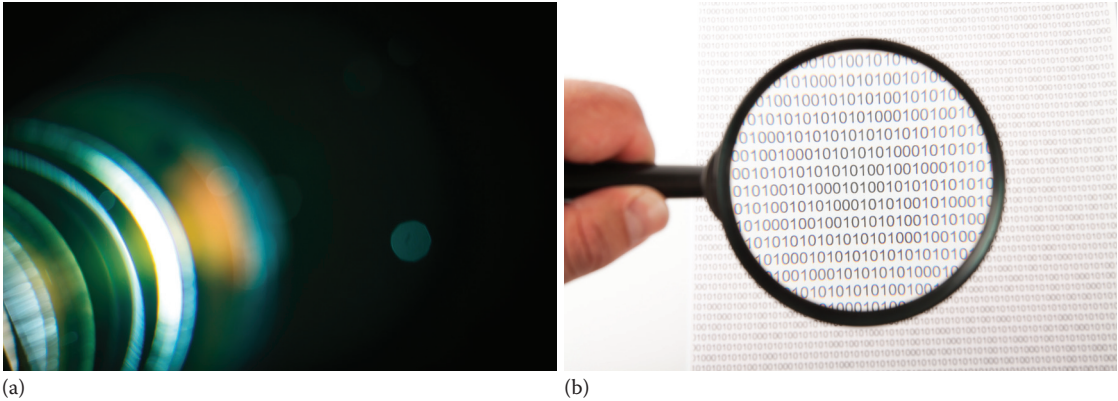


Figure L.82 Lens aberrations: (a) chromatic aberration and (b) spherical aberration.

Lens axicon focusing

[optics] Lens configuration that can provide BESSEL BEAM light propagation. This principle is used, for instance, in the precision alignment for large telescopes as well as in ultrashort laser pulse focusing. Additionally, the bar code scanners found in supermarkets use a LENS axicon for focusing a highly dispersive field resulting from the undefined surface properties (see [Figure L.83](#)).

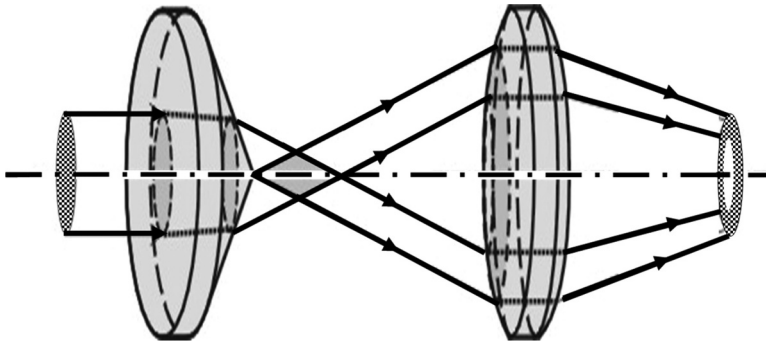


Figure L.83 Outline of lens-axicon focusing.

Lens maker's equation

[general] The equation describing the focal length (f) of an optical LENS as used by as a function of the radius of curvature of the incident surface (R_1) with respect to the exit surface (R_2) for a confined medium with index of REFRACTION n_2 when placed in an environment with index (n_1). For a thin lens this is expressed as $1/f = (n_2 - n_1)/n_1 \left[(1/R_1) - (1/R_2) \right] = P_{\text{power}}$, which yields the power P_{power} of the lens, that is, the “strength” of the lens as indicated by the optician making the lens for VISUAL ACUITY. Also known as the lens equation or thin lens formula. This equation was described by RENÉ DESCARTES (1596–1650). For a THICK LENS the refraction on either side of the medium will need to be accounted for, as well as the DISTANCE traveled before intersecting with the next curved surface. The lens maker's equation is derived

from geometry, to be $1/f = (n-1)\left[\left(1/R_1\right) - \left(1/R_2\right) + (n-1)t/nR_1R_2\right]$, where t represents the thickness distance of the optical path through the refractive medium with index of refraction n (see Figure L.84).

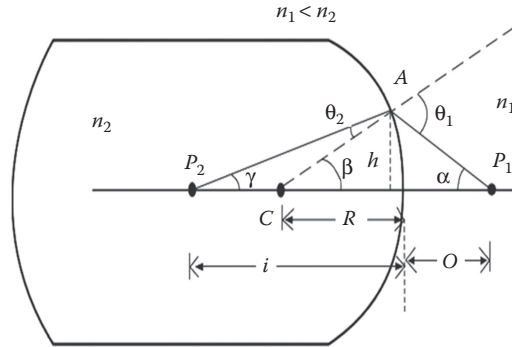


Figure L.84 Lens maker's equation concept.

Lens maker's equation

[general] The lens maker equation uses the REFRACTION concept to describe the formation of an IMAGE in a FOCAL POINT (f) of a system of aspherical surfaces with respective radii R_i using SNELL'S LAW as follows: $1/f = (n_2 - n_1)/n_1 \left[(1/R_1) - (1/R_2) \right] = P$, where n_1 is the index of refraction of the surrounding medium, n_2 the index of the refractive medium, and P the power of the LENS expressed in diopters. For a thin lens, the lens maker equation reverts to $(1/f) = (1/i) + (1/o)$, where i is the image DISTANCE to the lens and o is the object distance (see Figure L.85).

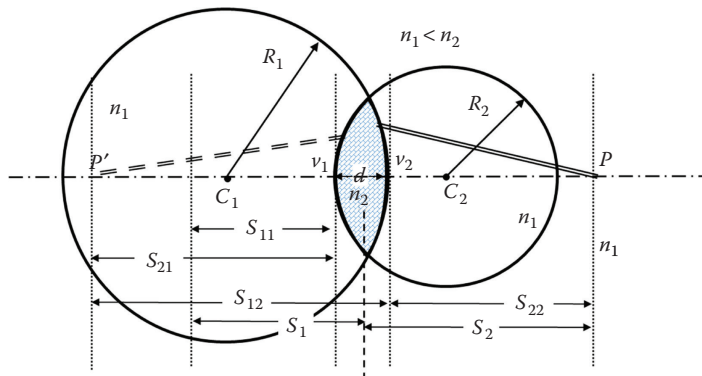


Figure L.85 Diagram representing the concepts used in the lens maker's equation.

Lenz, Heinrich Friedrich Emil (1804–1865)

[electromagnetism, general] Russian scientist with Baltic-German connection (Cyrillic name: Эмилий Христианович Ленц). In 1833, Lenz described the phenomenon that the induced electromotive force, or induced voltage, will produce a MAGNETIC FIELD that is opposite in direction of the change in magnetic

field that induces the voltage itself, which introduced the negative sign in the Faraday's law (see **LENZ'S LAW**) (see Figure L.86).



Figure L.86 Heinrich Friedrich Emil Lenz (1804–1865).

Lenz–Ising model

[solid-state] Theoretical model describing the PHASE TRANSITION for a uniaxial FERROMAGNET. Named after Wilhelm Lenz (1888–1957) and ERNST ISING (1900–1998). The MAGNETIC phase transition is a second-order phenomenon. The model uses a magnetic spin LATTICE configuration with lattice site Λ with respective spin locations $\square_j$, allowing only “up (+1)” or “down” (−1) spin: $\sigma_{\text{spin}} = (\sigma_{\text{spin}}^j)_{j \in \Lambda}$; $\sigma_{\text{spin}}^j \in \{-1, +1\}$. The model also describes the prevalence for neighboring spins to align, however, opposite alignment of a range of lattice locations can remain order (subcritical) or supercritical disordered state. Adjacent spins (i, j) , all within the lattice: $i, j \in \Lambda$ experience an external MAGNETIC FIELD B_i' , which is defined by an interaction parameter $\mathbb{I}_{ij}$. The total interaction can be described by the Hamiltonian: $H(\sigma_{\text{spin}}) = -\sum_{i,j} \mathbb{I}_{ij} \sigma_{\text{spin}}^i \sigma_{\text{spin}}^j - \mu_{\text{mag}} \sum_j B_j' \sigma_{\text{spin}}^j$, where the magnetic moment $\mu_{\text{mag}} = (-e/c)(v/2\pi r)(\pi r^2)$, where e electron charge in Coulomb, $c = 2.99792458 \times 10^8$ m/s the speed of light and r the radius of the orbit of an electron revolving with speed v . The PROBABILITY dissemination for the SPIN configuration is defined by a BOLTZMANN DISTRIBUTION $(P_{\tau_T}(\sigma_{\text{spin}}) = e^{-\tau_T H(\sigma_{\text{spin}})} / Z_{\tau_T})$, where $\tau_T = 1/k_B T$ with the Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23}$ m²kg/s²K and temperature T ; note $Z_{\tau_T} = \sum_{\sigma_{\text{spin}}} e^{-\tau_T H(\sigma_{\text{spin}})}$ is a NORMALIZATION factor combining the effects of all spins to yield a probability $0 \leq P_{\tau_T}(\sigma_{\text{spin}}) \leq 1$. A critical temperature can be identified, below which order will result in net magnetization. The full model cannot be solved analytically, unless severe assumption are made.

Lenz's law

[electromagnetism, general] Pertaining to a CURRENT (I) through a circuit running in loop, resulting from an electric field ($\vec{E}$) providing an ELECTROMOTIVE FORCE (ϵ_{emf}) with a resulting MAGNETIC FIELD ($\vec{B}$) passing through an area ($\mathcal{A}$, with normal $\vec{n}$) the following equation was defined: $\epsilon_{\text{emf}} = -(1/c)(d/dt) \int_{S_0} \vec{B} \cdot \vec{n} d\mathcal{A}$, where S_0 is the surface, $c = 2.99792458 \times 10^8$ m/s the speed of light, all with respect to time (t). Named after

HEINRICH LENZ (1804–1865) who introduced the concept in 1834. This is closely related to the Faraday's law (see [Figure L.87](#)).

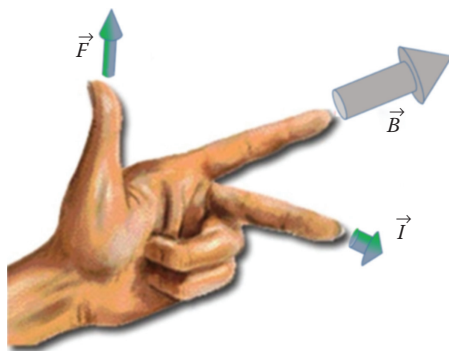


Figure L.87 The configuration of the orientation of the force on a moving charge (i.e., current) under the influence of a magnetic field under Lenz's law.

Leonardo da Vinci (1451–1519)

[fluid dynamics, general, mechanics] See **DA VINCI, LEONARDO**.

Leonards, Jack Rack (1919–1978)

[biomedical, chemical, fluid dynamics] Inventor and scientist from Canada. Leonard designed and verified the workings of a parallel plate dialysis machine in 1948 in collaboration with **LEONARD T. SKEGGS** (1918–2002). This type of artificial **KIDNEY** is different from the device developed by **WILLEM JOHAN KOLFF** (1911–2009) in the manner that it does not require a **BLOOD** pump.

Lepton

[astrophysics/astronomy, atomic, energy, general, nuclear, quantum, thermodynamics] Class of elementary **PARTICLE** generally without intrinsic net charge, except for the electron. Lepton are not subjected to the **STRONG NUCLEAR FORCE**, in contrast to the **MESON**, and hence does not bind in the nucleus. Examples of leptons are electron, **MUON**, tau particle, and **NEUTRINO**. Leptons have an intrinsic **SPIN** of 1/2 and hence obey the Fermi–Dirac definition.

Lepton, angular momentum of

[atomic, general, solid-state] Leptons have a small angular momentum that is measured in multiples of $b/4\pi$, where $b = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is Planck's constant.

Lepton number (L)

[astrophysics/astronomy, atomic, energy, general, nuclear, quantum, thermodynamics] **CONSERVATION OF CHARGE** designation for **ELEMENTARY PARTICLES** indicating the fact that for each Lepton (e.g., electron, **MUON**, tau) the equivalent charge must add up to same charge value on either side of the equation. For instance, for the following **PARTICLE** transition: $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$, where μ^- indicates a muon, e^- represent an electron, $\bar{\nu}_e$ is an electron anti-neutrino and ν_μ a muon **NEUTRINO**; the lepton number for the respective breakdown is represented as follows: $L_\mu: 1 = 0 + 0 + 1$ and $L_e: 0 = 1 - 1 + 0$.

Leucippus (fifth century BC)

[general] Scientist from ancient Greece, who in approximately 450 BC introduced the concept of the **ATOM** as the first documented entry of an elementary **PARTICLE** that contains all the characteristics of the object that consists of a multitude of these particles and is indivisible. The Greek word *atomos* (ατομος) means “that what cannot be cut further.”

Lever

[general, mechanics] A device used to provide torque by means of converting the force applied to one side of a bar that is hinging on a **FULCRUM** with respective **DISTANCE** to the same force in the opposite direction with a different distance to the fulcrum on the opposing site of the fulcrum. The radius pivoting on the elbow joint supported by the humerus while a force is applied by the biceps is a well-known example, as well as cranes hoisting equipment for construction (see [Figure L.88](#)).

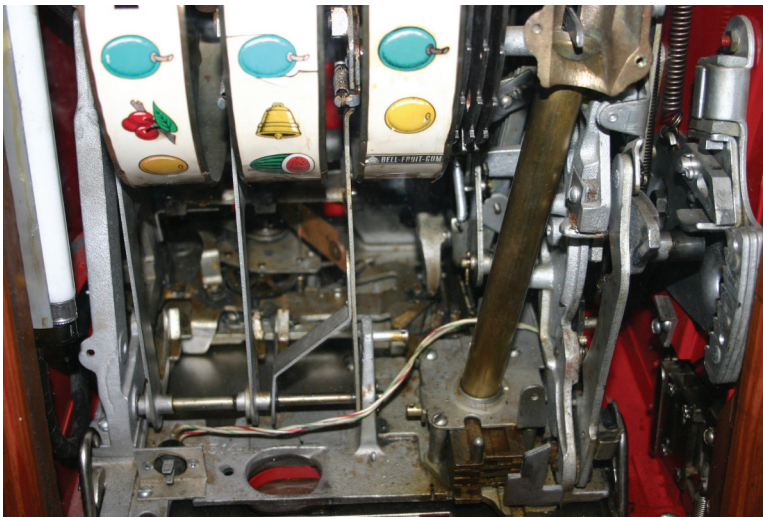


Figure L.88 Lever on slot machine.

Levinthal's paradox

[biomedical, computational, thermodynamics] Proteins are long chains of molecules (i.e., **MACROMOLECULES**, generally containing hundreds of atoms) that will configure themselves to establish a condition of **MINIMUM ENERGY** and entropy. Considering that a protein consisting of 2000 atoms will have 6000 degrees of freedom, 2/3 due to rotation and the remaining resulting from relative bond angles. Generally the protein structure may not appear to have an organized structure but the polypeptides do in fact have a structure as derived from **X-RAY** diffraction studies. The local amino acid sequences will most likely form stable interactions and will act as **NUCLEATION** points in the folding process. The regularity in the folding process, creating relatively fixed relative bond angles can be derived in Fourier space from the X-ray diffraction spectral analysis.

Levitation

[electromagnetism] The act of suspending an object in free space without anything attached, using a remotely operating force ($\vec{F}$). **MAGNETIC LEVITATION** can be achieved by means of electrical current which generates a magnetic field ($\vec{B}$) according to **LENZ'S LAW** ($\vec{F} = m \cdot \nabla \vec{B}$), which can, for instance, counteract

gravitational attraction (on a mass: m), provided there is enough symmetry to avoid lateral net forces. ELECTRIC CHARGE and MAGNETIC FIELD can exert a force without the requirement for direct contact. Levitation can be used to provide a low-friction interaction between two objects, for instance, in train transport. A mechanical suspension by means of AIR flow through a rail at closely separated interval is technically not considered to fall under levitation since there is a direct contact force involved resulting from the air flow (see Figure L.89).



Figure L.89 The concept of levitation, as a result of an external magnetic field, maglev train in Shanghai, with velocity exceeding 500km/h, respectively mainland China.

Lewis, Gilbert Newton (1875–1946)

[electromagnetism, general] Physicist and chemist from the United States, who is best known for his introduction of the word “PHOTON” for ELECTROMAGNETIC RADIATION in 1926. Lewis also worked on the definition of VALENCE electrons and introduced the concept of chemical bonds known as the covalent bond, and created the “Lewis symbols” used to describe ways in which atoms bond until this day. Lewis was the first to produce “HEAVY WATER” in the early 1930s with double-weight hydrogen atoms. The discovery of heavy water was essential in the experimental design for ATOMIC ENERGY (see Figure L.90).



Figure L.90 Gilbert Newton Lewis (1875–1946). (Courtesy of The Chemists' Club, New York.)

Lewis number ($Le = \kappa/D_{AB} = Sc/Pr$)

[fluid dynamics, thermodynamics] Dimensionless number indicating the ratio of the thermal DIFFUSION to the molecular diffusion, where κ is the thermal diffusion coefficient; D_{AB} the molecular diffusion coefficient for the constituent AB, as used in the FICK'S EQUATION; Sc the Schmidt number; and Pr the Prandtl number. Named after Warren K. Lewis (1882–1975).

Leyden jar

[electronics, general] Also known as the Leiden jar (Leyden being the old Dutch vernacular for the university city in the Netherlands now known as Leiden), dated for its use around 1745. A glass-jar device filled with a quantity of water, with a CONDUCTOR on the inside and on the outside of the container used in the early days of investigations in the collection of “electric fluid.” The Leyden jar conductors were attached to the Leyden jar forms the precursor to the modern day CONDENSER or CAPACITOR, as well as provided basic scientific evidence of storage of electrical charge leading to the invention of the BATTERY. The ELECTRIC CHARGE build-up (static ELECTRICITY) was accomplished by FRICTION of various materials. The first static electricity charge GENERATOR was developed by OTTO VON GUERICKE (1602–1682) in 1650 (see Figure L.91).

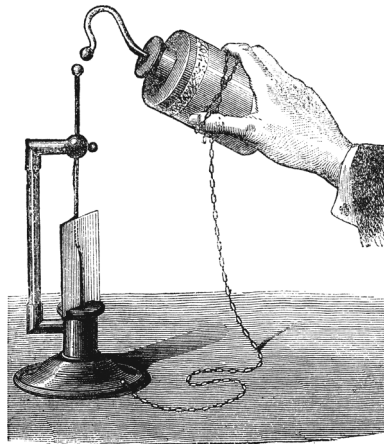


Figure L.91 Drawing of the original concept of the Leyden jar.

Libration point

[computational, general, geophysics] See LAGRANGIAN LIBRATION POINT.

Lifetime (τ)

[biomedical, nuclear] Average time of existence for RADIOACTIVE ISOTOPE. Tie over which the number of isotopes DECAY to e^{-1} : $\tau = \int_0^{\infty} t N_0 e^{-\lambda_{1/2} t} dt / N_0$, where $\lambda_{1/2}$ is the decay constant, t time, and N_0 the original quantity of isotopes (*also see* MEAN LIFE).

Lifshitz–Kosevich theory

[electromagnetism, quantum, solid-state] The RESONANCE component of an electrodynamic potential in the interaction on electrical RESISTANCE during CONDUCTOR exposure to an oscillatory MAGNETIC FIELD.

The MAGNITUDE of the electrodynamic potential is defined as $\Phi_{\text{osc}} = 2V_k T (eB/\hbar c)^{3/2} (\partial^2 S / \partial k_N^2)^{-1/2}_{\text{km}}$

$\sum_{j=1}^{\infty} \{ [\exp(-2\pi^2 j k_B T_D / \beta' B) / \sinh(2\pi^2 j k_B T_D / \beta' B)] * \cos[(j \hbar e S_m / eB) - 2j\pi\gamma \pm (\pi/4)] * \cos(j\pi g m_e^* / 2m_0) \}$, where S defines the cross-sectional surface of the Fermi area, $\beta' = e\hbar/m_e^* c$ is the Bohr double magneton, $m_e^* = \hbar^2 (\partial S / 2\pi \partial E)_{E_F}$ the CYCLOTRON effective mass, E_F the Fermi ENERGY, B the magnetic field strength, and E the energy on the FERMI SURFACE. This has relevance with respect to k -SPACE orbit

electrons, specifically in perpendicular direction to the magnetic field. One specific application is in the theoretical description of the functionality of MOSFET SEMICONDUCTORS.

Lift

[fluid dynamics] Force resulting from flow that provides the mechanism to raise an object subjected to fluid flow: $F_L = (1/2)\rho v_{\text{flow}}^2 AC_L$, where ρ is the FLUID density (e.g., accounting for altitude), A the surface area of the AIRFOIL (i.e., WING, or sail [horizontal force]), v_{flow} the relative AIR velocity (net velocity with respect to the wing, including for instance air flow and wing speed). This lift force describes the conditions for an airfoil to remain afloat during flight. Lift is a function of the density of the air, the FLOW velocity, next to the air's viscosity and compressibility, and the device parameters: the shape of the body, the surface area over which the fluid flows, and the inclination of the geometry of the body with respect to the flow. The influences resulting from geometric body shape, respective surface inclinations, fluid viscosity, and compressibility is a complex system. The lift coefficient designated can be used to account for the boundary conditions, providing a relatively simple equation. Lift on a rudimentary level is a direct result of the BERNOULLI'S EQUATION, where the path for fluid flow on the top is longer than the flow on the bottom of the object subjected to flow and resulting increased flow velocity on top, hence creating a pressure gradient in the upward direction, with effective lift force. At the position of the irregular object at the critical ANGLE with respect to direction of flow the lift will be maximized, also called angle of attack. Generally, a wing will have adjustment options (extension segments) that can change the angle of attack, while the wing itself remains fixed. The same will apply in a horizontal manner for a sail of a sailboat. The sailboat can adjust the angle of attack. Another example of an airfoil is a ski jumper. When the angle of attack grows, the separation point of the flow on the upper surface moves forward from the trailing edge toward the LEADING EDGE. On most airfoil shapes when the critical angle of attack is reached, the upper surface flow is more separated and the airfoil, sail or wing will produce the maximum lift coefficient. With increasing angle of attack, the upper fluid flow becomes more and more fully separated with a dramatic reduction in lift coefficient. When the airfoil wing angle exceeds the critical angle of attack, a condition with respect to airplanes results called stall, or lift stall. Also note that an airfoil can be symmetric and still maintain lift, specifically due to the lift-angle, which artificially increases the path length on the upper side. Airplanes can hence fly upside-down depending on the wing symmetry and lift angle. Even for symmetric objects (round, square, etc.) a situation can occur that produces lift due to CIRCULATION vortices that result in a condition of zero flow velocity at a point in the proximity of the surface of the object, with resulting Bernoulli pressure gradient: $\Delta P = -\int_0^{2\pi} P \sin(\theta) a d\theta = \rho \kappa_{\text{circ}} v_{\text{flow}}$, where κ_{circ} represents the cyclic constant defining the circulation and a is a constant. The cyclic constant is linked to the VELOCITY POTENTIAL (ϕ) as $\phi = \kappa_{\text{circ},0}\omega + \kappa_{\text{circ},1}\omega' + \kappa_{\text{circ},2}\omega'' + \dots$, where ω' defines the CIRCULATION FUNCTION in a specific location, a specific circuit. The circulation function is not the "CIRCULATION" related to vortices (see Figure L.92).



Figure L.92 Lift on an object (i.e., plane) subjected to flow.

Lift, stalling angle

[fluid dynamics] The **ANGLE** of the wing (moveable **WING** or angle of ascent of the plane) for **AIRFOIL** shapes when the critical angle of attack is reached. At this point, the upper surface flow is more separated and the airfoil has surpassed its point of maximum **LIFT** coefficient. Increasing angle of attack beyond the stalling angle will cause the upper **FLOW** pattern to detach with a dramatic reduction in lift coefficient. Beyond this angle the lift will reduce and the plane will not elevate. The stalling angle of lift (stalling angle of attack; attack angle) for most airfoils has a characteristically value of approximately 15° . Another example of an airfoil is a ski jumper. The ski jumper quickly reduces in velocity due to the **AIR DRAG** that the whole-body experiences (see [Figure L.93](#)).

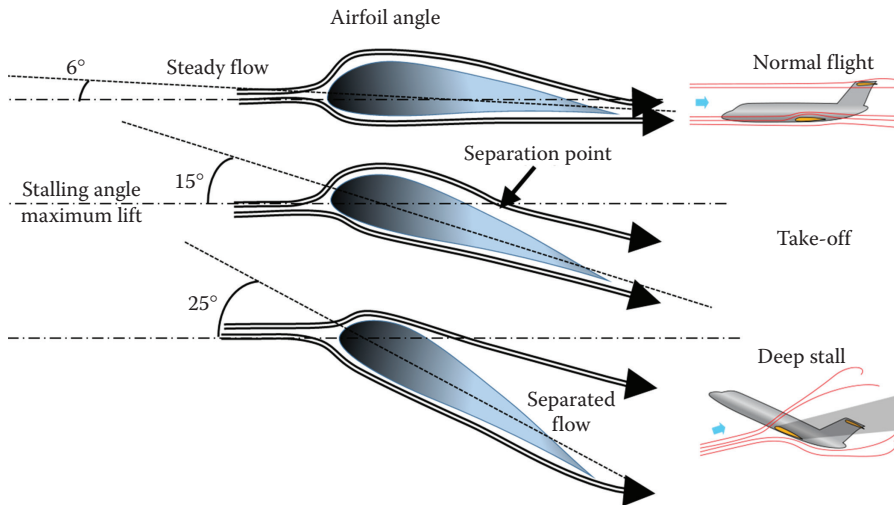


Figure L.93 Illustration of the effect of airfoil angle with respect to fluid flow; stalling angle for Lift.

Lift coefficient (C_L)

[fluid dynamics, general] Number used to account for the impact on **LIFT** of all of the complex dependencies of curvature, shape, as well as particular **FLOW** conditions. This number follows from rearranging the lift equation. Coefficient in an equation that describes the threshold limit for airborne lift force (F_L) of an object outfitted with wings, as described in the following equation: $F_L = (1/2)\rho v^2 A C_L$, where ρ is the **FLUID** density (e.g., accounting for altitude), A the surface area of the **AIRFOIL** (i.e., **WING**), v the **AIR** velocity (net velocity with respect to the wing, including for instance air flow and wing speed). This lift force describes the conditions for an airfoil to remain afloat during flight. The lift coefficient is defined as a function of the **ANGLE** of incidence, or the wing angle with respect to the airflow in addition as a function of **MACH** NUMBER and **REYNOLDS** NUMBER, describing the local fluid conditions (e.g., **HUMIDITY** and fluid mixture: **RAIN**). At a specific altitude, the velocity needs to exceed the **ORBITAL** VELOCITY to remain in lift, the point at which the flight velocity equals the orbital velocity is called the Kármán line. The lift

coefficient is defined as $c_\ell = 2F_L / \rho v^2 A$, where F_L is the lift for the wing with surface area A , under relative flow velocity v (see Figure L.94).

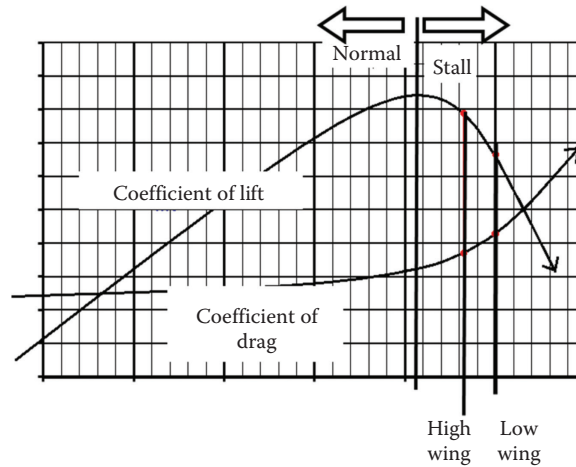


Figure L.94 Lift coefficient and lift–drag ratio.

Lift–drag ratio

[fluid dynamics] Amount of lift (L) experienced by an AIRFOIL, divided by the viscous DRAG (F_{drag}) generated by the FLUID it moves through. The ratio of the LIFT force with respect to the drag RESISTANCE is a scaling marker of the aerodynamic efficiency of for instance an airplane. Under normal conditions, the optimal conditions are described as $(L/F_{\text{drag}})_{\text{max}} = (1/2)(\pi A_r \epsilon_{\text{span}} / C_{D,0})$, where A_r is the aspect ratio (ratio of the length to the chord [“width”] of a curved surface, note for an airplane both wings are involved: wingspan), ϵ_{span} the span efficiency factor, and $C_{D,0}$ the “zero lift drag coefficient.” The zero lift drag coefficient is a dimensionless parameter as a function of the size, shape, and velocity of the object: $C_{D,0} = C_D - C_{D,i} = [\epsilon_1 \xi_{\text{prop}} W_p / (1/2) \rho_0 \sigma_{\text{density}} S] - [C_L^2 / \pi A_r \epsilon_{\text{span}}]$, where $\epsilon_1 = 2091.3$, ξ_{prop} the PROPULSION efficiency, W_p the ENGINE power (i.e., “trust,” the rate at which work is performed $W_p = d\text{Work}/dt = d(Fs)/dt$, where s is the DISTANCE over which the force acts), ρ_0 the fluid density, σ_{density} the compensation factor for altitude with respect to AIR on density, and S the surface area of the WING. The span efficiency factor for a long wing is close to unity. For a Boeing 747, the lift–drag coefficient is approximately 17 at mach 0.85 = 1041 km/h. For supersonic or hypersonic flow conditions the LIFT–DRAG RATIO $(L/F_{\text{drag}})_{\text{max}} = 4(M+3)/M$, where M is the MACH NUMBER. For the Concord flying at mach 2 the lift–drag ratio was approximately 7. The drag force is a function of the REYNOLDS NUMBER (Re): $F_{\text{drag}} \approx k v$, for $Re < 1$; $F_{\text{drag}} = (1/2) D_d A \rho v^2$, for $Re > 1000$, where $D_d = \text{constant}$ the DRAG COEFFICIENT (Note: not a general constant), A the area perpendicular to the FLOW, and v the relative flow velocity (also see LIFT COEFFICIENT).

Ligament

[biomedical, mechanics] Connective tissue, collagen based, that forms a fibrous connection between several bones and JOINTS. In contrast, tendons are fibrous tissues that connect bones or other organs (e.g., the EYE), to MUSCLE tissues (see [Figure L.95](#)).

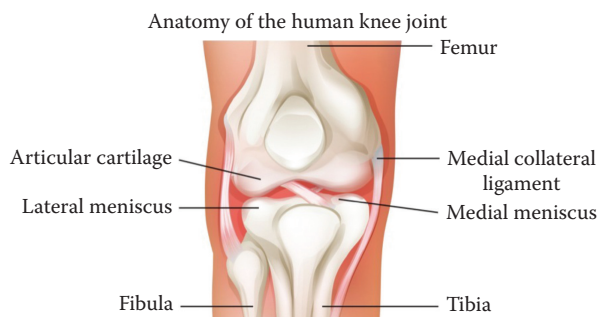


Figure L.95 Knee ligament.

Ligand

[biomedical, chemical] Dipole molecule or molecular chain that will bind to specific ELEMENTS or larger chemical entity. The ligand specifically provides a “chemical key” in biological cellular-facilitated DIFFUSION. In certain cases, the chemical ADHESION enables solubility of a MOLECULE such as protein, in which case they are referred to as “soluble factors.” Frequently, the ligand is charged (electron excess or deficit) thus providing a strong chemical binding opportunity. Next to providing solubility the ligand provides the mechanism to the transport chemical constituents through biological cellular membranes, for example, ligand-gated channels. Ligands occur in natural as well as artificial form. Artificial ligands can be designed for drug delivery. In biology for CELL MEMBRANE transport the ligand binds with specific receptor chemical chains, which will facilitate the opening of a channel in the MEMBRANE, but is not necessarily the chemical that is transported. Hemoglobin is a ligand that facilitates the transport and release of oxygen. Another example is nicotine, which binds to nicotine–acetylcholine receptor (nAChR) resulting in the formation of an ION CHANNEL supporting the increased transmission of, for instance, potassium, calcium, and sodium ions. Biological entities rely on ligand-mediated channels to support functions such as pain, sleep, memory, and anxiety. Pharmacological drugs and illicit drugs use the same mechanism to provide an altered state (see [Figure L.96](#)).

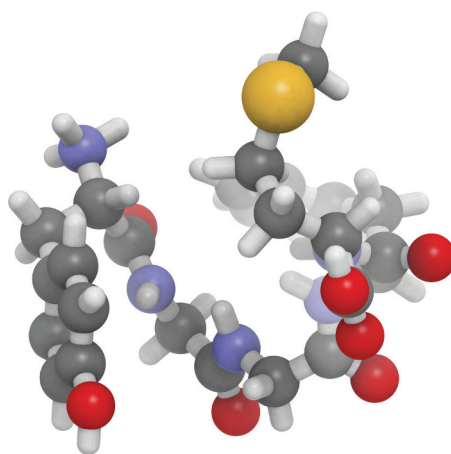


Figure L.96 Illustration of the met-enkephalin molecule, an endogenous ligand that provides pain receptors with functionality. Enkephalin molecules are small peptides.

Ligand field

[chemical, electronics, solid-state] The electric field originating from the LATTICE structure based ION configuration in crystalline structures. The crystal structure imposes a deviation from the single metallic ion field based on the groups of molecules and ions that form the lattice structure, named ligands. The ligand field primarily result from electrons in the $(3d)^3$ orbital setting. (Note: BOHR ATOMIC MODEL.) One example is found for the manganese(II) oxide, for the Mn^{2+} ion, which is surrounded by six O^{2-} ions configured in a octahedral structure, hence 6 ligands. The influence of the ligands cause the DEGENERACY of the electron ORBITAL ANGULAR MOMENTUM, with associated Stark effects in the ENERGY spectrum.

Light

[electromagnetism, general, optics] ELECTROMAGNETIC RADIATION emitted as the result of an accelerating charge. General light is considered the visible spectrum of electromagnetic radiation, ranging from approximately 320–680 nm in WAVELENGTH (λ). The entire ELECTROMAGNETIC SPECTRUM ranges from approximately 10^{-13} m, classified as Gamma rays (γ rays), to radio waves and power lines with wavelength up to 10^5 m. The shorter the wavelength, the higher the ENERGY (E) in the WAVE mechanism captured as $E = h\nu = h(c/\lambda)$, with frequency ν , $c = 2.99792458 \times 10^8$ m/s the speed of light, and $h = 6.62606957 \times 10^{-34}$ m²kg/s Planck's constant. Since light is the combined effect of both alternating electric field and MAGNETIC FIELD the MAGNITUDE cannot be expressed as “intensity,” since intensity is defined as the AMPLITUDE squared. The following definitions are used in expressing the magnitude of electromagnetic radiation, based on energy density. The irradiating power density is defined as the luminous irradiance: I . The irradiance is the rate of FLOW of ELECTROMAGNETIC ENERGY radiation or radiant power, expressed in Watt, that is incident on a surface area. The irradiance is expressed in Watts per square meter ($[W/m^2]$), alternatively in Joules per square meter SECOND ($[J/m^2s]$). The default irradiation power profile is a Gaussian distribution as a function of DISTANCE to the central axis ($\vec{r}$), in direction $\vec{s}$, primarily in the far-field for a POINT SOURCE and more specifically for a laser source: $I(\vec{r}, \vec{s}) = I_0 e^{-(2r^2/\omega_0^2)} e^{ik \cdot \vec{s}}$, I_0 the irradiance at the center of the spot/beam, $k = 2\pi/\lambda$ the wavenumber for wavelength λ , and ω_0 the “waist” of the (laser) beam. This is under the assumption that the irradiance profile is symmetric around the principal axis. The concept “waist” defines a beam that contracts and expands over a specific distance. The waist for a focused beam of ordinary light is linked to the FOCAL POINT of a LENS system, yielding the spot size radius in the FOCAL PLANE. For a laser the waist is linked to the laser design configurations and the inherent DIVERGENCE ANGLE ($\theta_d = M_b^2 4\lambda/\pi\omega_0$, for a single mode beam: TEM₀₀, where M_b is a factor representing the beam-propagation ratio, generally close to 1). For a rectangular beam, such as delivered by an excimer laser, both edges of the rectangle have a Gaussian beam profile (see Figure L.97).

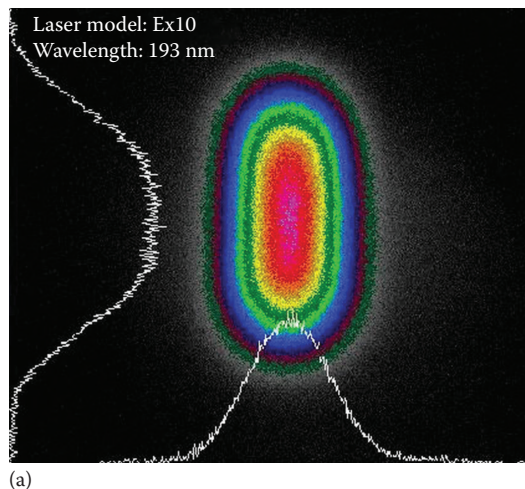


Figure L.97 Rectangular beam profile for an Excimer laser output, courtesy GAM Laser.

(Continued)



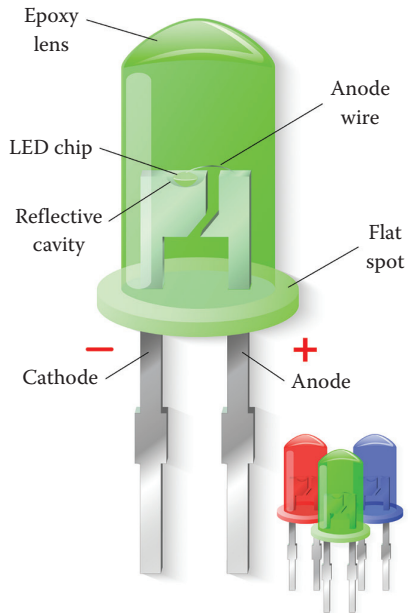
(b)

Figure L.97 (Continued) (b) Illustration of the use of artificial and natural light in the city of Shanghai, China.

Light emitting diode (LED)

[electronics, solid-state] Semiconductor material that will emit light under an applied electric field. A positive–negative BARRIER (i.e., *pn*-JUNCTION) provides a band gap that can be influenced by an applied voltage across the junction. The applied voltage generates an electric field that lowers the barrier, allowing a current to FLOW, as in a normal DIODE. The movement of electrons across the *pn*-barrier takes place under acceleration, hence emitting ELECTROMAGNETIC RADIATION. LEDs are predominantly made from ELEMENTS in the III-A and V-A groups of the periodic tables. For instance n-doping of gallium phosphate (GaP) can be made to emit light in the green spectral range. LEDs are available from 260 nm to mid-infrared, the short wavelength still being the most difficult and least efficient. General electrical conversion efficiency ranges from 0.1% to 60%. Single LEDs are available in broad range visible light with several watt of light emission. The high-powered LEDs are rapidly replacing the low efficiency incandescent light bulbs. Semiconductor material structure that uses the *pn*-junction to generate light, relying on the fact that accelerating charges emit electromagnetic radiation. An eternally applied electric field (which is a function of the applied voltage) causes the free electrons to migrate through the *pn*-barrier, recombining periodically with “holes” in effect continuously accelerating and decelerating. The use of specific semiconductor materials will define the junction conditions and hence the ENERGY threshold and as such the required external field that needs to be applied to generate light, and what the emitted frequency range will be based on the energy balance. Short-wavelength LED require a higher electrical potential than long wavelength diodes. A RED LED

(broadband: 610–640 nm) will operate at roughly 1.8–2.2 V drop (current approximately 20 mA), whereas a blue (broad-band: 420–480 nm) LED requires in excess of 3.7 V (see [Figure L.98](#)).



(a)



(b)

Figure L.98 (a) Light emitting diode design and (b) example of LED applications.

Light guide

[general, optics] Structure that will allow light to be transported from an entry point to a release area to provided localized illumination. Most transparent objects can provide light-guiding action, even the **FLOW** of water. An example of water as a light guide can be observed, in particular, for the stream of water from a faucet can capture the light that is incident on the outside surface of the flow at an **ANGLE** that will refract the light in the direction of the flow, thus making the light subject to **REFLECTION** of the water–air interface. The water flow as a light guide can be observed in the kitchen faucet when spot lights (e.g., halogen LED) are mounted above the faucet area. The area where the water flow reaches the sink surface will be illuminated much brighter than the surrounding “dry” area inside the sink (*also see FIBER-OPTIC*) (see [Figure L.99](#)).

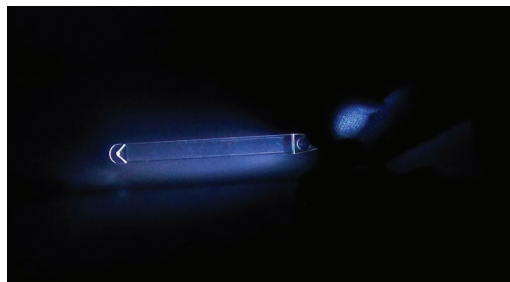


Figure L.99 Light guide example. Clear plastic wand used to illuminate the surgical area, such as a blood vessel during an operation procedure.

Light source

[general] Many objects can be included in the list describing objects that emit visible light. Next to visible all object emit infrared RADIATION as a function of their temperature, when the temperature becomes high enough, the wavelengths associated with the supplied ENERGY reduce to the visible. One example of visible light emitted from a warm object is the use of electric heater coils and the incandescent lamp. Normal room temperature visible light emitters are found in phosphors and LEDs. The velocity of light in media is frequently a function of wavelength and for a broad spectral source this may result in DISPERSION. The Sun is the most well-known LIGHT SOURCE, mechanism of action based on nuclear reactions and generated plasmas. Since the Sun is primarily composed of helium (He) and hydrogen (H₂), at a temperature of 5780 K, providing the fuel and operating conditions to power a NUCLEAR REACTOR (i.e., FUSION REACTOR), fusing hydrogen with helium. The electromagnetic spectral emissions from the Sun span an extensive range, approximately from less than 100 nm to about 1 mm. Next to the solar ELECTROMAGNETIC RADIATION, the nuclear events also produce charged PARTICLE emissions. Chemical reactions can produce light as well, the firefly being the most well-known example of this phenomenon. Other examples of light sources are found in electric discharge (neon lamp, LIGHTNING) and electric potential. The emission of light resulting from a changing electrical potential is for instance obtained by the rapid unwinding of adhesive tape, generating a high electric field at the point of separation, which causes electrons to be accelerated and produce light at very short wavelength. Generation of light adheres to the LAW OF CONSERVATION OF ENERGY (see [Figure L.100](#)).



Figure L.100 General light source assortment, from left to right: candle, incandescent bulb, fluorescent bulb, and LED bulb.

Lightning

[energy] Natural phenomenon creating an electronic discharge through AIR from the earth's surface to the clouds, as well as cloud-to-cloud, resulting from a significant POTENTIAL DIFFERENCE. Lightning is an electric current in free space ionizing FLUID (*also see* ARC, CORONA, and SPARK). (see [Figure L.101](#))



(a)



(b)

Figure L.101 Lightning events: (a) Macintosh Lake, Longmont Colorado and (b) lightning near wind turbine.

Limelight

[general, optics, thermodynamics] Heated lime stick (calcium oxide and calcium hydroxide, respectively) emitting ELECTROMAGNETIC RADIATION based on the Planck radiation law. The lime is heated by burning hydrogen, merged with pure oxygen to temperatures exceeding 2570°C . The phenomenon was discovered in the 1820s by the chemist and inventor Goldsmith Gurney (1793–1875) from Great Britain, using the flame of the OXIDATION of hydrogen, also described by the scientist and engineer Robert Hare (1781–1858) from the United States, in the early 1820s. The limelight is also attributed to the contributions by the civil engineer Thomas Drummond (1797–1840) from Great Britain, who built a working prototype in 1826 to be used for land surveying. The work of Thomas Drummond was inspired by efforts from the English scientist MICHAEL

FARADAY (1791–1867). Also known as Drummond light, or calcium light. The limelight was used frequently in concert halls and theater's, hence the reference “being in the limelight” (see [Figure L.102](#)).

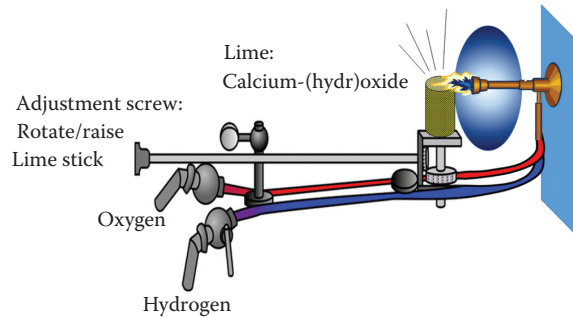


Figure L.102 Limelight resulting from heating (calcium oxide) lime to high temperature, in excess of 2572 °C, generating spectral emissions based on the Planck's radiation law with peak emission wavelength depending on the temperature of the lime defined by Wien's displacement law, with radiance defined by the Stefan–Boltzmann law.

Lindbergh, Charles Augustus (1902–1974)

[biomedical, general, mechanics] Explorer and scientist for the United States. Lindbergh is most known for the first solo transatlantic flight in 1927. Many years later Lindbergh teamed up with the French vascular surgeon ALEXIS CARREL (1873–1944) to develop and produce the first known heart–lung machine in 1935 (see [Figure L.103](#)).



Figure L.103 Charles Augustus Lindbergh (1902–1974). (Courtesy of Library of Congress.)

Linde–Hampson liquefaction cycle

[thermodynamics] Refrigeration cycle used to form liquid from vapor. The cycle consists of five stages: (1) isothermal compression; (2) isobaric cooling; (3) isenthalpic EXPANSION; followed by (4) isotropic separation of the liquid phase from the VAPOR phase, with subsequent (5) isobaric compression back to the point of origin. The fraction of liquid (Y_{fridge}) produced is a function of the inflow of vapor ($\dot{m}_g$, i.e., the FLOW rate of mass of GAS through the compressor), the rate of extraction of liquid ($\dot{m}_l$), the heat of vaporization (h_v),

and the specific enthalpie of the LIQUID and the gas respectively (h_ℓ ; h_g): $Y_{\text{fridge}} = \dot{m}_l / \dot{m}_g = (h_v - h_g) / (h_v - h_\ell)$ (see Figure L.104).

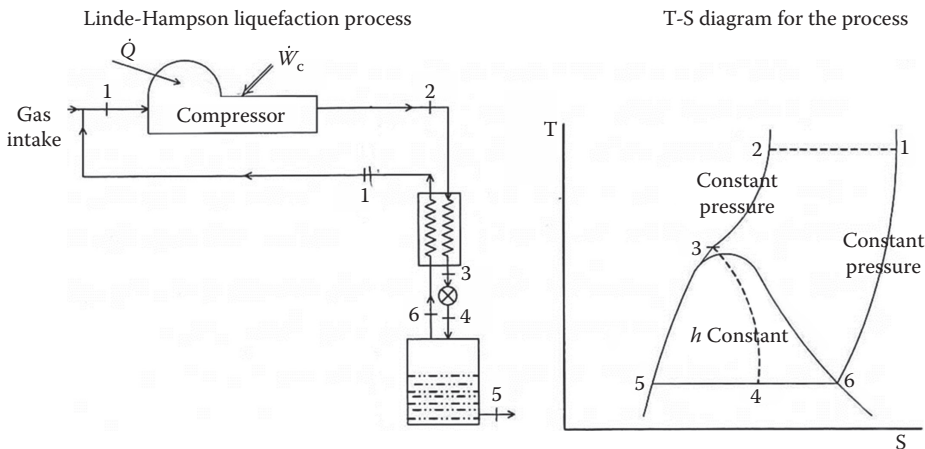


Figure L.104 Linde–Hampson liquefaction cycle.

Line of response (LOR)

[imaging] Detection path associated with the positron emission TOMOGRAPHY mechanism of action, in which two 511 keV Gamma rays are emitted from one location that travel in exact opposite directions. The co-location detection of the GAMMA RAY pair by means of two detectors provide the identification mechanism of the source and hence the origin of the event leading the phenomenon targeted for imaging (see Figure L.105).

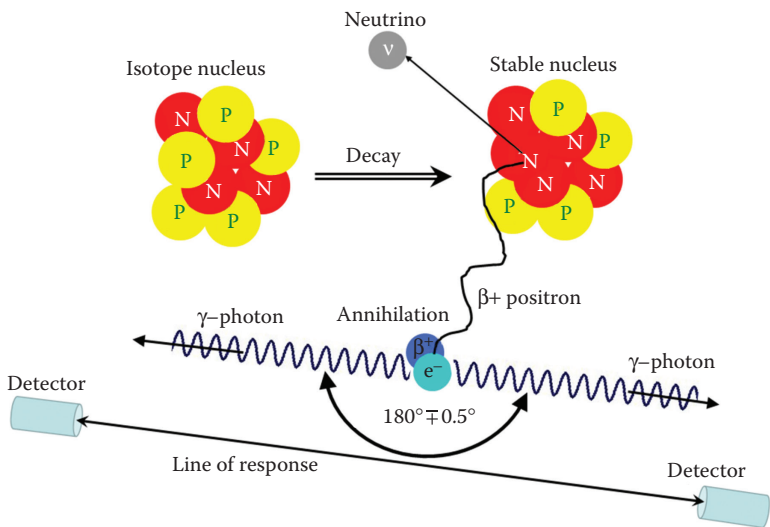


Figure L.105 Line of response for the gamma pair emitted during positron emission excitation under PET imaging.

Line of stability

[general, nuclear] Plot of atomic number against NEUTRON number that represents the stable nuclides (see Figure L.106).

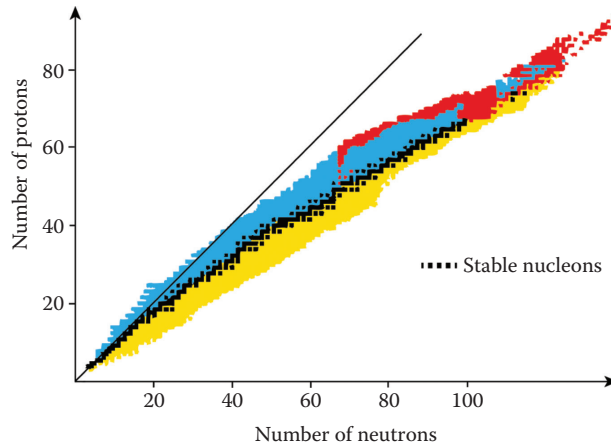


Figure L.106 Line of nuclide stability.

Line spectrum

[atomic, chemical, energy, mechanics, nuclear, optics, quantum, thermodynamics] Characteristic ELECTROMAGNETIC SPECTRUM emitted by a luminous gas or VAPOR with distinct lines representing the various ELEMENTS contained in the GAS. The emission may be artificially induced by an applied electric or MAGNETIC FIELD or resulting from collisions. This mechanism is used in optical SPECTROSCOPY for identification purposes. Alternatively, the absorption lines of a medium exposed to an electromagnetic source with a known and well-defined spectrum can also be used for atomic and molecular identification. Emission lines of atomic excitation. The following spectral line configurations can be identified (named after the first person to discover the phenomena and publish on the data and the mathematical basis). The relationship between the respective emission line, the excitation state and the atomic configuration in question follows a quantum mechanical analysis based on the BOHR ATOMIC MODEL. The following spectral line emissions can be identified: LYMAN SERIES: $\nu = cR \left[\left(\frac{1}{1^2} \right) - \left(\frac{1}{n^2} \right) \right]$ and $n = 2, 3, 4, 5, \dots$ ultraviolet; BALMER SERIES: $\nu = cR \left[\left(\frac{1}{2^2} \right) - \left(\frac{1}{n^2} \right) \right]$ and $n = 3, 4, 5, \dots$ visible; PASCHEN SERIES: $\nu = cR \left[\left(\frac{1}{3^2} \right) - \left(\frac{1}{n^2} \right) \right]$ and $n = 4, 5, 6, \dots$ infrared; Brackett series: $\nu = cR \left[\left(\frac{1}{4^2} \right) - \left(\frac{1}{n^2} \right) \right]$ and $n = 5, 6, 7, \dots$ infrared; PFUND SERIES: $\nu = cR \left[\left(\frac{1}{5^2} \right) - \left(\frac{1}{n^2} \right) \right]$ and $n = 6, 7, 8, \dots$ infrared; Humphreys series: $\nu = cR \left[\left(\frac{1}{6^2} \right) - \left(\frac{1}{n^2} \right) \right]$; and $n = 7, 8, 9, \dots$ far INFRARED. In all these the following constant apply and n is an integer indicating the

excited level in the Bohr model, $R = 10,967,758 \text{ m}^{-1}$ is the RYDBERG CONSTANT, $c = 299,792,458 \text{ m/s}$ the speed of light is an integer depicting the excitation levels. The condition $n = \infty$ represents IONIZATION (see Figure L.107).

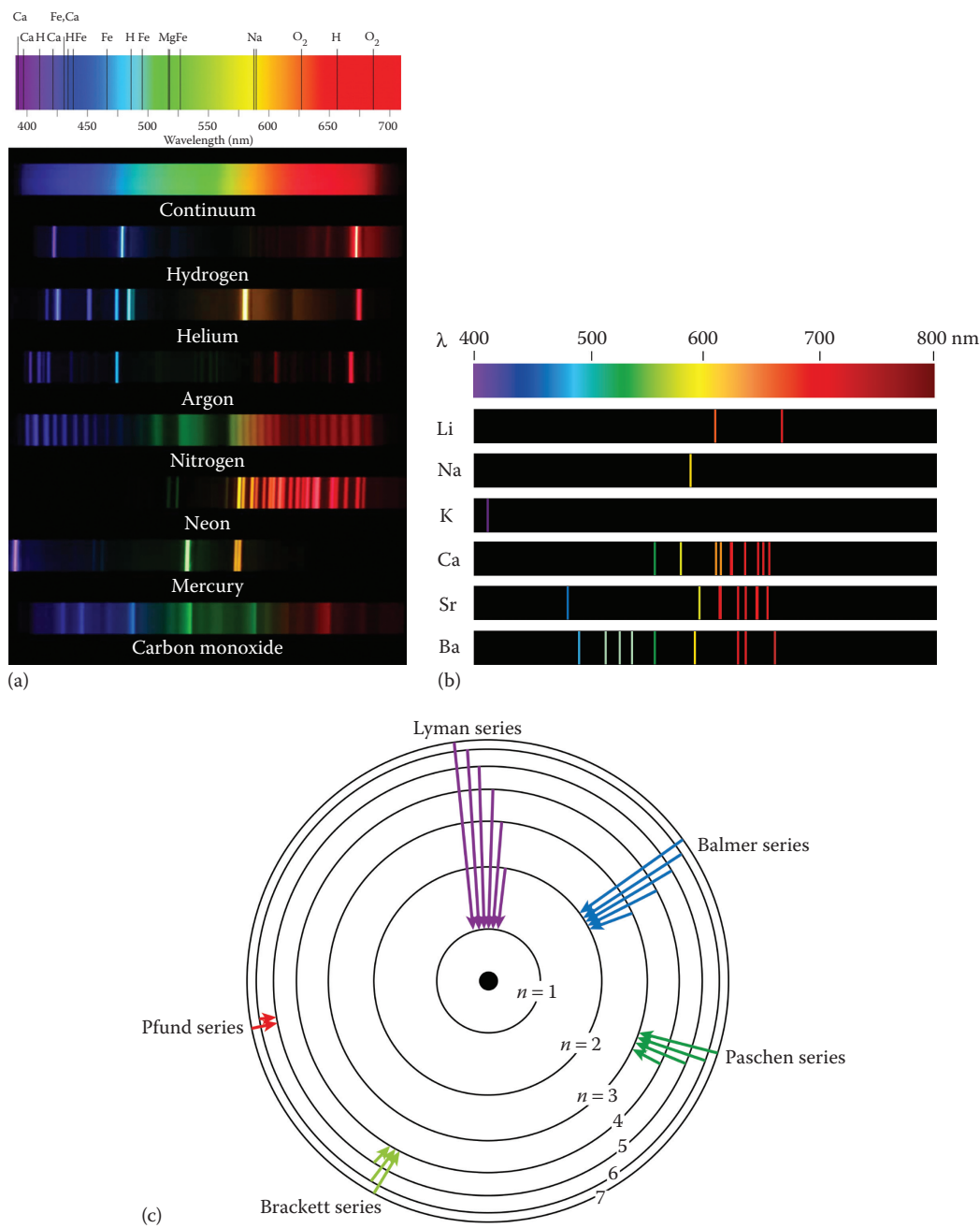


Figure L.107 (a) Diagram of the assorted Line spectra, (b) various element spectra, and (c) hydrogen spectrum; as described by the Rydberg formula, composed of the Lyman, Balmer, and Paschen series.

Line strengths

[general] Breaking strength (i.e., tension) in a rope or cable. Generally the LOAD on a cable (e.g., NYLON, Dacron, and other polymers) should not exceed one-fifth of the breaking-strength or one-sixth for hemp rope.

Line voltage

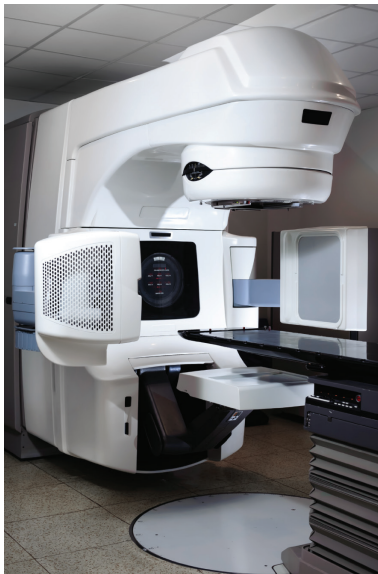
[general] The voltage (i.e., electrical potential) applied to the supply line leading to a facility (e.g., house, factory; voltage at the socket in the house). In the United States, Canada, and northern South America, the line voltage is between 100 and 127 V, in Europe, Africa, southern South America, Africa, and Asia it ranges from 220 to 240 V. Some countries have regional variability and offers both 120 or 220 V. The alternating frequency also varies, primarily it is either 50 or 60 Hz.

Linear absorption coefficient (μ_a)

[acoustics, general, nuclear, optics] The DECAY constant in the quantity of particles, phonons, photons, or other ENERGY in a linear path due to a material obstruction with fixed thickness (d). The attenuation is the result of extinction, and is directly proportional to the incident quantity (I_o), based on the heuristic relationship: $I = I_o e^{-\mu_a d}$, known as the Beer–Lambert Law. When considering loss due to SCATTERING, while maintaining full or partial energy content the effect is referred to as attenuation (see LINEAR ATTENUATION COEFFICIENT).

Linear accelerators

[atomic, nuclear] Particle accelerator that has a virtually infinite path length, based on a loop configuration with negligible losses due to radial acceleration. Particles are launched in an evacuated tube that has electric field and MAGNETIC FIELD gradients that are used for lensing/steering, next to providing the acceleration mechanism. The forces providing the acceleration are either Lorentz force, Coulomb force, or the “MAGNETIC FORCE” (also SYNCHROTRON or CYCLOTRON) (see Figure L.108).



(a)



(b)

Figure L.108 (a) Linear accelerator in hospital setting, used in cancer treatment and (b) large-scale linear particle accelerator, Bates linear accelerator; Cambridge, MA. The accelerator provides a high-intensity beam with narrow energy band electrons providing the tools for extremely accurate fine structure measurement of the nucleus of atoms.

Linear attenuation coefficient

[acoustics, biomedical, general, nuclear, optics] The DECAY constant in the quantity of particles (including charged particles), phonons, photons, or other ENERGY in a linear path due to a material obstruction with fixed thickness (d). The attenuation is the result of the combined and indistinguishable effects of extinction, redirection (e.g., SCATTERING, collision or deflection by electric or MAGNETIC fields, such as COMPTON EFFECT) and partial energy loss, and is directly proportional to the incident quantity (I_o), based on the heuristic relationship: $I = I_o e^{-\mu_a d}$, known as the Beer–Lambert law.

Linear beamforming

[acoustics, biomedical, computational, electromagnetism] This expression has two separate meanings: (1) In SIGNAL processing the linear beamforming aspect involves the control of the directional response of the emission or detection of a signal on a TRANSDUCER array by means of driver control or phased-detection algorithm. (2) In ENERGY emission (phonons or photons) the arrangement of emitters constructs an organized pattern of emission, using either a piezoelectric array in acoustical imaging of an ANTENNA array in radio transmission, using INTERFERENCE or other techniques of spatial filtering to control the beam pattern and matching the sensing configuration to the emitter design for optimal RESOLUTION. In sonar applications, the linear beam can selectively probe. In radar the beamforming has both signal processing and signal formation with associated device design aspects.

Linear charge density (λ_{charge})

[general] Number of charges per unit length for a one-dimensional charge distribution, for instance on a wire, defined as $\lambda_{\text{charge}} = Q/L$, where Q is the total charge and L the length over which the charge is distributed.

Linear congruential random number

[computational] Random number resulting from an algorithm that uses a linear equation as a base. The number is the result of a multiplier and a constant additive applied to incremental input array of numbers.

Linear energy transfer (LET)

[biomedical] In the interaction of radiation with MATTER the linear ENERGY transfer describes the energy dissipation per unit length (x) traversed through the medium per photon energy: E (i.e., spectrally resolved) defined as $LET = dE/dx$. The linear energy transfer is a direct function of the density and three-dimensional chemical composition of the medium. Frequently water may be used as a calibration agent. Not all biological media have the same response function to radiation of various energy levels and for this the equivalent dose was introduced, measured in Sievert (Sv). In general the exposure to radiation is quantified in a cumulative manner for determination of radiation exposure risks.

Linear expansion, temperature coefficient of (α_{thermal})

[general] The ratio of the length after exposure to a different temperature (new length: L_{new}) has created an equilibrium situation with respect to the equilibrium situation under the original boundary conditions with original length (L_0): $\alpha_{\text{thermal}} = (L_{\text{new}} - L_0)/L_0$.

Linear filter

[acoustics, computational] Computational mechanism of smoothing either by means of averaging, with a Gaussian weighted average, or by means of the use of a derivative.

Linear momentum (p)

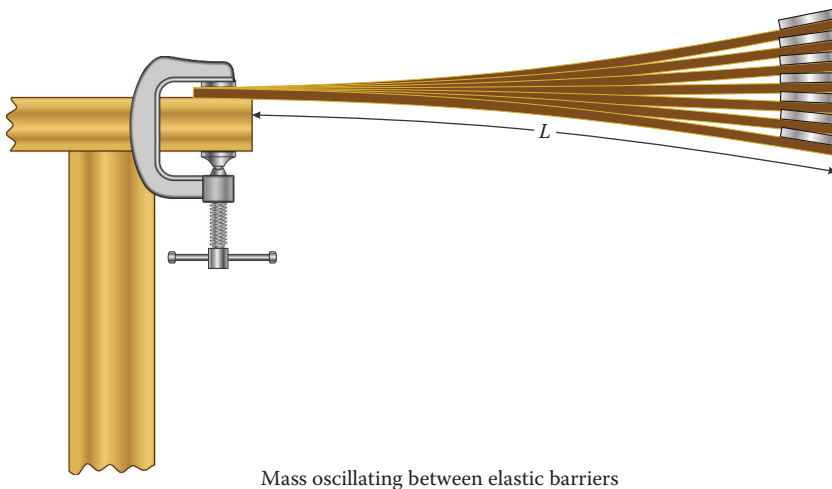
[general, mechanics] One-dimensional momentum p , where $p = mv$ is the mass of an object moving with linear velocity v . In linear momentum, ALGEBRA opposed to directed momenta will cancel out the equal MAGNITUDE. The rotational equivalent of linear momentum is angular momentum, the moment of momentum: L , where $L = I\omega$ is the MOMENT OF INERTIA and ω the ANGULAR VELOCITY. Also ω , where $L = r_{\perp}p$ is the length of the arm of rotation, and the linear momentum changes direction incrementally, but can be observed as a constant in the tangential direction.

Linear operator

[atomic] A mathematical procedure that obeys the computational distribution: $r_{\perp}$ where $\mathbb{O}(f + g) = \mathbb{O}(f) + \mathbb{O}(g)$, and f are functions, as well as g , with $\mathbb{O}(tf) = t\mathbb{O}(f)$ a SCALAR.

Linear oscillator

[atomic, nuclear] Vibration and propagation in a two-dimensional system. The VIBRATION will occur in one direction only with propagation in the orthogonal direction. The QUANTUM harmonic oscillator is the quantum-mechanical equivalent of the classical linear oscillator. In QUANTUM MECHANICS the existence of an arbitrary potential can in most cases be approximated by a harmonic potential oscillating around a stable equilibrium point. The quantum harmonic oscillator provides an important tool in modeling in quantum mechanical systems. In quantum mechanics the WAVE-EQUATION is replaced by an operator function equation; the Hamiltonian ($\hat{H}$), expressed for a PARTICLE in a POTENTIAL WELL as $\hat{H}$, where $\hat{H} = \left(\hat{p}^2/2m\right) + (1/2)m\omega^2\hat{x}^2$ the ANGULAR VELOCITY of the OSCILLATION, m the mass of the particle (e.g., electron) m , is the quantum operator for momentum with $\hat{p} = -i\hbar(\partial/\partial x)$, where $\hbar = h/2\pi$ Planck's constant, for velocity $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ and x the location operator. The solutions contain EIGENVALUE that are linked to the SCHRÖDINGER EQUATION with quantum number $\hat{x}$ confined solutions. This process also applied to phonons (*also see* HARMONIC OSCILLATOR) (see [Figure L.109](#)).



Mass oscillating between elastic barriers

Figure L.109 Representation of the phenomenon of linear oscillation.

Linear polarization

[general] Polarization is a property of ELECTROMAGNETIC RADIATION, indicating the direction of the electric field. Linear polarization has a fixed, single direction of the electric field. The linear polarized light results from a LINEAR OSCILLATOR. Laser light is generally linearly polarized due to the excitation and oscillatory selection mechanisms. This stands against unpolarized light and elliptically polarized light.

Linear regression

[computational] Mathematical method to illustrate the relationship between a function: n , which is generally a SCALAR-dependent parameter, in relation to one or more root parameters $f: \vec{x}$, where $f(x) = a\vec{x} + b$ and a are constant. The linear regression is an approximation to a distribution of data-points that are apparently within close proximity to a straight line, and the approximation will have a confidence level indicating the “goodness of fit.” The goodness of fit is indicated by the linear correlation coefficient (b). The closer R is to 1 the better the fit.

Lines of force

[general, mechanics] In a force diagram, the direction of the forces with respect to the location on a body that they respectively act on, which may in some cases be the center of mass.

Lineweaver–Burk plot

[biomedical] Algebraic tool to derive the rate constant for a chemical reaction of enzyme kinetics, based on a graphical approximation (linearization, approximating “LINEAR REGRESSION”) to the representation of binding site with respect to the maximum number of binding site in the reaction expressed by the nonlinear empirical relation: R^2 (which yields a hyperbolic curve), where $B_{\text{sites}} = L_0 B_{\text{max}} / (K_d + L_0)$ is the number of “free” LIGAND receptors (meaning unbound), and L_0 the number of ligand-bound receptors, B_{sites} (Note: after dissociation the ligand and binding site are as original state) the “equilibrium dissociation constant,” and K_d = quantity of dissociated ligand bounding events per SECOND/quantity of ligand binding events per second the maximum number of ligand binding sites. The plot is the graphical expression of the Lineweaver–Burk equation, described by Hans Lineweaver (1907–2009) and Dean Burk (1904–1988) in 1934 (also see MICHAELIS–MENTEN EQUATION) (see Figure L.110).

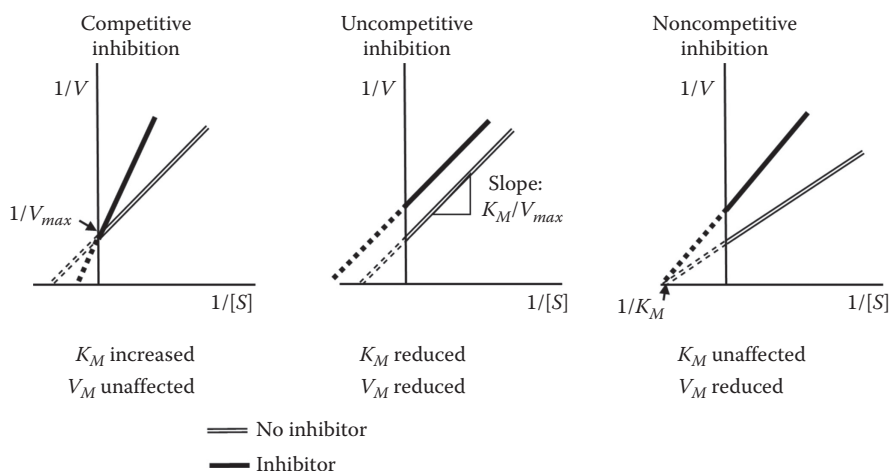


Figure L.110 Lineweaver–Burk plot for enzyme kinetics.

Liouville, Joseph (1809–1882)

[acoustics, computational, fluid dynamics, mechanics] Mathematician and physicist from France. In computational formalism (i.e., number theory), Liouville proved the existence of transcendental numbers as the first, using continued fractions. The continued fractions are known as Liouville numbers. In mathematical PHYSICS, Liouville worked with JACQUES CHARLES FRANÇOIS STURM (1803–1855) to produce the Sturm–Liouville theory. The STURM–LIOUVILLE TECHNIQUE is a standard procedure to solve certain types of integral equations

by developing into eigenfunctions. The second physics contribution was his description on how time evolution is measure preserving for a Hamiltonian system, known as Liouville's theorem. (see [Figure L.111](#))



Figure L.111 Joseph Liouville (1809–1882).

Liouville function

[computational] Principle used in number theory to solve linear equations in the theory of analytic functions. The concept was apparently first published by AUGUSTIN LOUIS CAUCHY (1789–1857) in 1844 and verified by Liouville in 1850. For function $(B_{\max})$ in multidimensional space $(f(x))$ the absolute value is confined in a series as $x \in C^n$, where $|f(x)| \leq M(1 + |x|^m)$ is bound and confined in time by the condition $f(x)$ (also see **LIOUVILLE'S THEOREM** or **LIOUVILLE EQUATION**).

Lipperhey, Hans (Lippershey) (1570–1619)

[biomedical, optics] Scientist and optical engineer from Germany. Lipperhey (also found “Lippersheim”) perfected the optical compound microscope introduced by ZACHARIAS JANSEN (1580–1640). He increased the magnification to 600 times and mitigated some of the aberrations and distortions. This was a fundamental step in investigative science, and specifically biological examination (see [Figure L.112](#)).



HANS LIPPERHEY.
secundus Confractionum inventor.

Figure L.112 Hans Lipperhey (1570–1619), also found as Lippershey and Lippersheim.

Lippmann–Schwinger integral

[acoustics] In acoustical imaging the scattered ($df(\vec{x})/dt = 0$) pressure ($p(\vec{x}, v)$) as a function of the location vector $f(\vec{x}, v) = p(\vec{x}, v)/\rho(\vec{x})$ and imaging FREQUENCY ($\vec{x}$), with location specific density v with respect to the incident beam $\rho(\vec{x})$ and total field $f(\vec{x}, v)^{\text{inc}}$, can be solved by taking the integral over the scattering potential ($f(\vec{x}, v)$) as $\gamma(\vec{x}, v)$, where $f(\vec{x}, v)^{\text{scat}} = f(\vec{x}, v) - f(\vec{x}, v)^{\text{inc}} = -\int k_{\lambda} \gamma(\vec{x}', v) f(\vec{x}', v) g(|\vec{x} - \vec{x}'|) d^2 \vec{x}'$ is the wavenumber, and k_{λ} the GREEN'S FUNCTION for free space, with $g(|\vec{x} - \vec{x}'|) = (i/4) H_0^{(1)}(k_{\lambda}(|\vec{x} - \vec{x}'|))$ the zero-order HANKEL FUNCTION.

Liquefaction

[fluid dynamics, solid-state, thermodynamics] Solid-state PHYSICS: to liquefy (change phase from solid to liquid). Water liquefies at $H_0^{(1)}$, the liquefaction temperature of helium is 273.13 K = 0°C. GEOPHYSICS: the transformation of the mechanical properties of soil reached during an EARTHQUAKE, the solid mass converts into an amalgam resembling a suspension and has the behavior of a LIQUID with FLUID dynamic properties (see Figure L.113).



Figure L.113 Melting ice.

Liquid

[general] Homogenous medium of single-phase materials at a fixed temperature for all constituents. One of the four phases of materials: solid, liquid, vapor, and PLASMA. The liquid phase is a FLUID phase, allowing for random deformation with little effort and is generally incompressible. Vapor is also a fluid, but this is compressible. Vapors can be condensed to form a liquid using a compressor, on the other hand generally gases cannot. The ENERGY released during condensation is the SPECIFIC HEAT of condensation, which is not necessarily equal to the specific heat of vaporization. The liquid phase is a function of temperature, volume and pressure conditions and can be outlined in a PT diagram (pressure (4.2K) vs. temperature (P)); known as PHASE DIAGRAM) and a PV diagram (pressure [T] vs. volume [P]). In the PT diagram at the TRIPLE-POINT the here phases of liquid, vapor, and solid can all exist in equilibrium. A solid converting into liquid is defined as melting, while the conversion of VAPOR into liquid is condensation. Each PHASE TRANSITION has its own energy requirements depending on the material/molecular composition. The conversion process are a function of temperature, pressure and volume, respectively. The transitions and coexistence of multiple phases for multiple constituents is defined by Gibbs phase rule. GLASS is a special form of liquid, a super-cooled liquid, not a crystalline structure. The Van der Waals description of a liquid follows from the EQUATION OF STATE, modified from the ideal GAS LAW: V , where $[P + (a/V^2)](V - b) = RT$ is the universal gas constant, and $R = 8.3144621(75) \text{ J/Kmol}$ and a are material specific constants, with b an indication of MAGNITUDE of cohesive forces between the molecules in a GAS and a the volume of the molecules.

Liquids can FLOW, however with certain restrictions on the minimum ORIFICE size. A liquid has a special characteristic at the surface called SURFACE TENSION. Surface tension is the work requirement associated with an increase in surface area of a liquid. Since molecules are attracted by their neighbors, at the surface this attraction is only operating in b direction, with a net inward-directed force. Surface tension provides a mechanism for objects that have a higher density as a solid can still float on the liquid; an aluminum sheet will float on water, and water striders “walk” on water. Surface tension also provides a mechanism that will make a liquid drop form a spherical configuration; the sphere has the greatest volume for the smallest surface area, adhering to the internal COHESION forces. Certain liquids are polar, they have a charge distribution, such as ALCOHOL (water is polar on a molecular level, the asymmetric 2π steradian, with net charge distribution: DIPOLE). Other liquids are nonpolar, making them relatively inert, with no net charge effects (e.g., OIL). On a stress level in the classical description of a fluid, the material must continually flow or deform, under any shear stress. A polar fluid does not behave this way, it can withstand shear stress. A number of fluids do behave this way, VISCOELASTIC and BINGHAM PLASTIC fluids can withstand shear stress. Cement paste, which is typically a Bingham plastic, must first reach a yield stress before it will flow. The polarity will influence the VELOCITY POTENTIAL and vorticity of a liquid in MOTION where polarity couples to the stress TENSOR in a way that generates torques in the equation of motion. A liquid will expand in all direction with equal extension, providing the volumetric EXPANSION coefficient: H_2O , for the expanding volume $\gamma = \partial V / \partial T$ with regard to the applied change in temperature V ; sometimes also found as T (see Figure L.114).

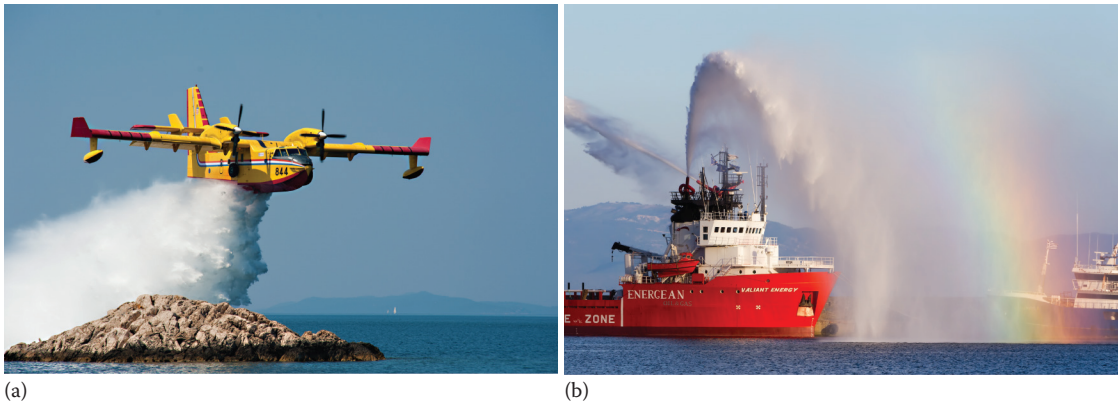


Figure L.114 Liquid form of aggregation: (a) water used to extinguish a fire when dumped from a firefighter airplane and (b) water sprayed from rescue ship, showing the Sun strike the water from behind the point of view, creating a rainbow resulting from light refraction.

Liquid, compression waves in

[general] Due to the incompressible nature of liquids a transverse WAVE will have to rely on an EXPANSION of the LIQUID in the lateral direction at a crest and contract in a trough.

Liquid crystal display (LCD)

[atomic, nuclear] Amorphous material structure that resembles the properties of both liquid and solid. LCD screens use backlit nematics or calamitic liquid crystals as the optical medium that provides the mechanism for light modulation. Calamitic liquid crystals consist of rod-like molecules. This attribute allows for light manipulation due to the anisotropic nature of calamitic liquid crystals. Historically imide-based polymers have been the calamitic liquid crystal of choice. Frequently LCD semiconductor devices use a more flexible polydimethylsiloxane (PDMS, a silicon-based organic ELASTOMER) as the gelatinous light-transmitting structure. LCD screens are subdivided in individual illuminating ELEMENTS, called pixels. Each PIXEL consists of a layer of molecules aligned between two transparent electrodes.

Additionally, the “liquid crystal” are sandwiched between polarization filters which are positioned in perpendicular fashion. The electrodes make the LIQUID crystal perform OPTICAL ACTIVITY, changing the polarization, otherwise without the liquid crystal, light passing through the first polarization filter would be blocked by the transverse second polarizer. Generally the POLARIZATION of the light emitted from an LCD computer screen is at β ANGLE (see Figure L.115).

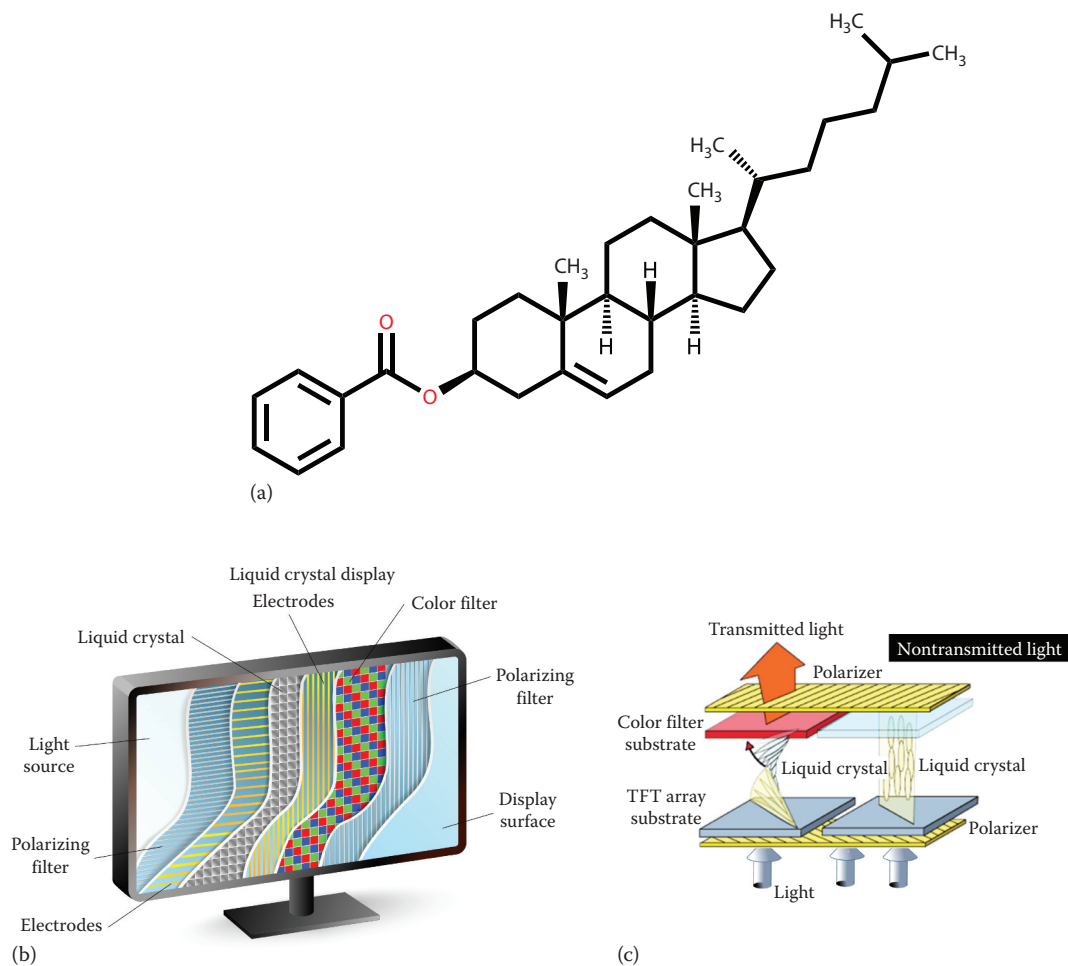


Figure L.115 (a) Liquid crystal display elemental component: cholesteryl-benzoate, one of various liquid crystal molecules, (b) general outline of the LCD screen design, and (c) LCD screen.

Liquid drop model

[atomic, nuclear] Atomic model defined by NIELS HENRIK DAVID BOHR (1885–1962) and JOHN ARCHIBALD WHEELER (1911–2008) in 1939 describing the NUCLEUS as a symmetric liquid drop that confines the charges under a perceived SURFACE TENSION, with specific size dependent ENERGY content. The model forms the basis of the NUCLEAR FISSION description that was experimentally verified only a few months earlier. The general assumptions were that the nucleus is incompressible, making the radius proportional to the three-root of the charge (45°), this yields charge density of $r_{\text{nucleus}} \sim \sqrt[3]{A}$, where $\rho_{\text{change}} = Ze/(4/3)\pi r^3$ is the atomic number and Z the PROTON charge. Additionally the forces between the

charges (protons) and neutrons in the nucleus (nucleons) were identical for all nucleons, and that the NUCLEAR FORCE has asymptotic SATURATION (see [Figure L.116](#)).



Figure L.116 Liquid drop model, once the individual droplets congeal they form a continuum.

Liquid form of aggregation

[thermodynamics] Vapor condenses to form droplets. All LIQUID drops are in the same PHASE and all droplets are in equilibrium. When bringing droplets together they will form a liquid. The medium is above the triplet point in the PV PHASE DIAGRAM (see PHASE DIAGRAM).

Lithium

[general, solid-state] Chemical ELEMENT with atomic number $e = +1.60217657 \times 10^{-19} C$. Lithium is a METAL and the lightest metal known and was discovered by Johan August Arfwedson (1792–1841) in 1817 in the mineral petalite ($Z = 3$). The electron structure for lithium is $LiAl(Si_2O_5)_2; 1s^2$.

Lithography

[general] An IMAGE is carved on a plate which is wetted with water and subsequently coated with ink on the “image” aspects of the plate, the water fills the “nonimage” or blank areas of the image to be transferred. The ink is transferred to a rubber roller, which in-turn transfers the image to paper, this is referred

to as off-set printing (offset lithography); not transferred directly from the plate to paper (as in gravure printing) (see [Figure L.117](#)).

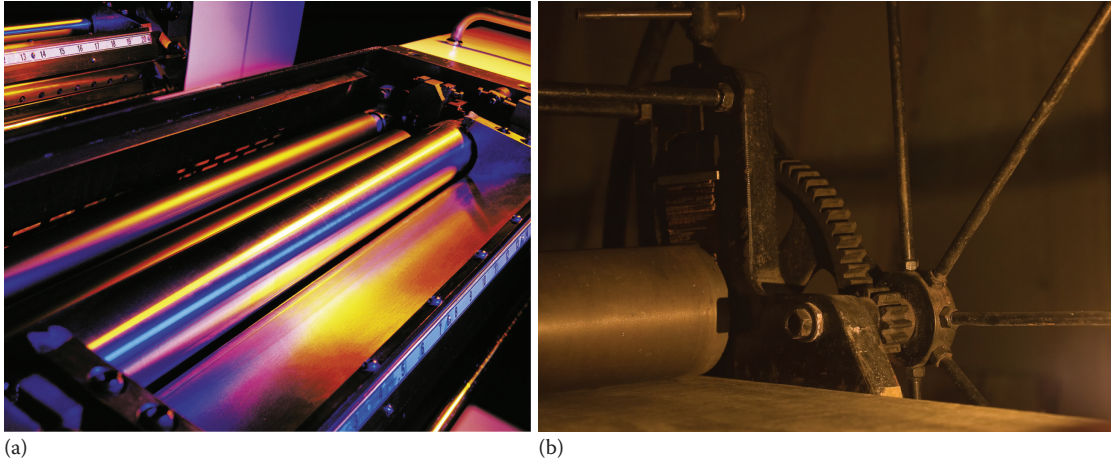


Figure L.117 (a) Offset print press, using lithographic plates to transfer the image onto paper and (b) close-up of old lithographic printing press.

Liver

[biomedical, chemical] Biological (visceral) organ that provides a service in protein synthesis as well as BLOOD purification and filtration. In the filtration aspect the liver can detoxify blood, and in this manner handles ALCOHOL. Alcohol processing will take a toll on the liver, making the liver susceptible to disease. The liver is predominantly found in vertebrate animals but is also found rarely in certain nonvertebrate animals. The liver also plays an invaluable role in producing the enzymes and chemicals needed in the digestive processes (see [Figure L.118](#)).

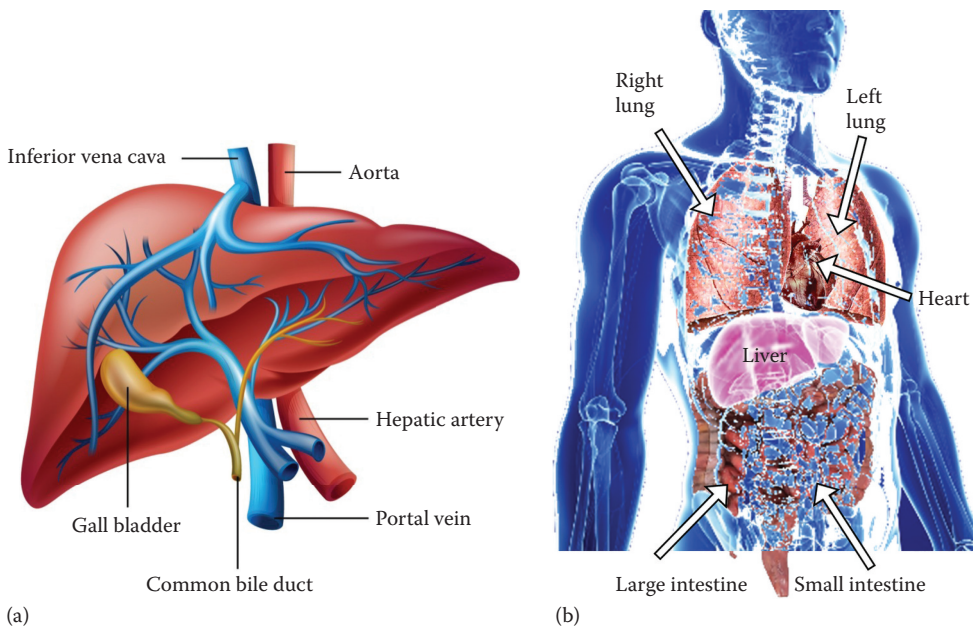


Figure L.118 (a) Anatomical diagram of liver and (b) location of the liver in the human anatomy.

LLLT

[biomedical, energy, optics] See LASER BIOSTIMULATION and LOW-LEVEL LIGHT THERAPY.

L-meson

[atomic, nuclear] HADRON group of bosons within the ELEMENTARY PARTICLES with BARYON NUMBER 0. Mesons are made up of quarks and are classified into dozen types of hadrons. Mesons experience all range of interacting forces: GRAVITY, weak, electromagnetic and strong. The L-meson is generally defined as MUON or PION ($2s^1$). The lightest mesons fall in the L-meson category: π -meson.

Load

[general, mechanics] Force exerted in a direction that is perpendicular to the contact surface that supports the object or device.

Load resistor

[general] Resistor in electronic circuit that is applied externally to the device that provides a voltage or current source for power generation. The load resistor can be the equivalence RESISTANCE of a light bulb.

Lockhart–Martinelli number ($\pi^-; \pi^0; \pi^+$)

[fluid dynamics, general, mechanics, thermodynamics] Dimensionless number signifying the LIQUID fraction applying to two-phased flow, where $\chi = [(1-x)/x](\rho_g/\rho_\ell)(\eta_\ell/\eta_g) = (\dot{m}_\ell/\dot{m}_g)\sqrt{\rho_g/\rho_\ell}$ is the liquid fraction; x the KINEMATIC VISCOSITY; η and ℓ representing the liquid and GAS PHASE, respectively; g is the liquid phase mass flow rate; $\dot{m}_\ell$ the gas phase mass flow rate; m_g the density of the GAS or vapor; and ρ_g the density of the liquid. This parameter is useful in refrigeration, the cooling FLUID in the compressor flow (also see CARNOT ENGINE).

Lodestone

[general] Term used to describe the early discovery of naturally occurring magnets. Also known as magnetite, an iron oxide (ρ_ℓ).

Lodge, Oliver Joseph, Sir (1851–1940)

[general] Scientist and physicist from the United Kingdom who provided critical ELEMENTS in the development of wireless communication technology, as well as telegraphy (see Figure L.119).

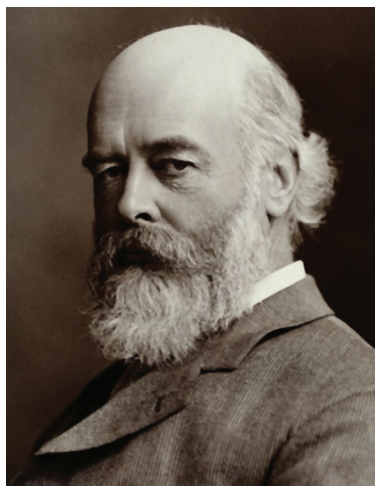


Figure L.119 Sir Oliver Joseph Lodge (1851–1940).

Logarithm

[computational] Mathematical concept introduced by John Napier in 1614 (e -log) and Henri Briggs in 1624 (10-log), however they were close friends and colleagues, making the distinction rather arbitrary and we may consider it a joint venture. The logarithmic base can be Fe_3O_4 , ($e = \sum_1^n (1 + (1/j!)) \cong 2.718\dots$) respectively “natural log”-based or “10-based” (also used as “common” logarithm). The logarithmic base is essential in describing phenomena that occur in nature. Generally, only the logarithm of prime numbers is needed to describe a SOLUTION of a MAGNITUDE, the nonprime numbers can be derived by addition and multiplication. The logarithm of a number is the exponent to which the base needs to be raised to obtain the root number. The logarithm (log) of an exponential expression brings the exponent as a multiplier: $n \rightarrow \infty$; respectively: $\log_e a^k = k \log_e a = k \ln a$, and $\ln e = 1$.

Logarithmic dependence

[general] Nonlinear behavior of a function, or PERCEPTION. The human EAR is logarithmic in its response (common log), meaning that for a SOUND to be perceived as twice as loud the pressure AMPLITUDE needs to be 10 times the baseline, similar to the HUMAN EYE. Gauges can be made to be logarithmic in response due to mechanical or electronic design that requires 10 times the force to travel a fixed DISTANCE (spring) or, respectively the voltage response is decimal in following a current change.

Logarithmic derivative of wave function

[computational, nuclear] Mathematical mechanisms used to solve for wave-functions at boundary conditions. The logarithmic derivative transforms a function to the ratio of the function's derivative and the function itself: $\log_{10} 10 = 1$. At boundaries both the function and the first derivative are required to be continuous and hence this function provides the ideal approach. The SOLUTION will still require NORMALIZATION/scaling.

Logarithmic mean temperature difference (f'/f)

[thermodynamics] Parameters used to define the HEAT TRANSFER. The concept is used specifically in heat exchangers. The logarithmic mean temperature difference is defined as LMTD, where $\text{LMTD} = [(\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2)] (1/2)$, respectively ΔT_1 are the temperature differences in a cold and a warm steam of the exchange, entering and exiting the system.

Logarithmic velocity distribution

[fluid dynamics] Velocity distribution in turbulent flow discovered by LUDWIG PRANDTL (1875–1953). The logarithmic flow is the third layer in a four layer model, from the WALL outward: viscous-layer (~laminar flow), transition layer, turbulent logarithmic layer, and turbulent outer layer. In the logarithmic velocity layer the FLOW velocity has a logarithmic (not “normal”) distribution and the total shear stress (ΔT_2) is proportional to the DISTANCE to the wall (i.e., depth $[\tau_{\text{tot}}]$ for ONE-DIMENSIONAL FLOW; e.g., water running ashore, creating ripples in the sand): z , where $\tau_{\text{tot}}(z) = \tau_b [1 - (z/b)]$ is the distance from the sea level surface to the bottom of the ocean (i.e., beach) and b the bottom shear stress. The velocity (τ_b) profile under these conditions satisfies: v , where $dv/dz = \sqrt{\tau_b/\rho} / \kappa_{\text{Karman}} z$ the density and ρ the Karman constant, which yields: κ_{Karman} with $v = (\sqrt{\tau_b/\rho} / \kappa_{\text{Karman}}) \ln(z/z_0)$ a constant indicating the depth at which the average velocity equals zero.

Logistic map

[computational] Elementary form of a chaotic process for obtaining a number from another number (z_0) in a computational system expressed as: y_n .

Long waves in canals

[fluid dynamics] Waves in narrow passage of water that can be approximated as a uniform depth canal with parallel walls and a smooth river bed (*see* CANAL WAVE, TIDAL WAVE, and TIDAL BORE WAVE) (*see* Figure L.120).

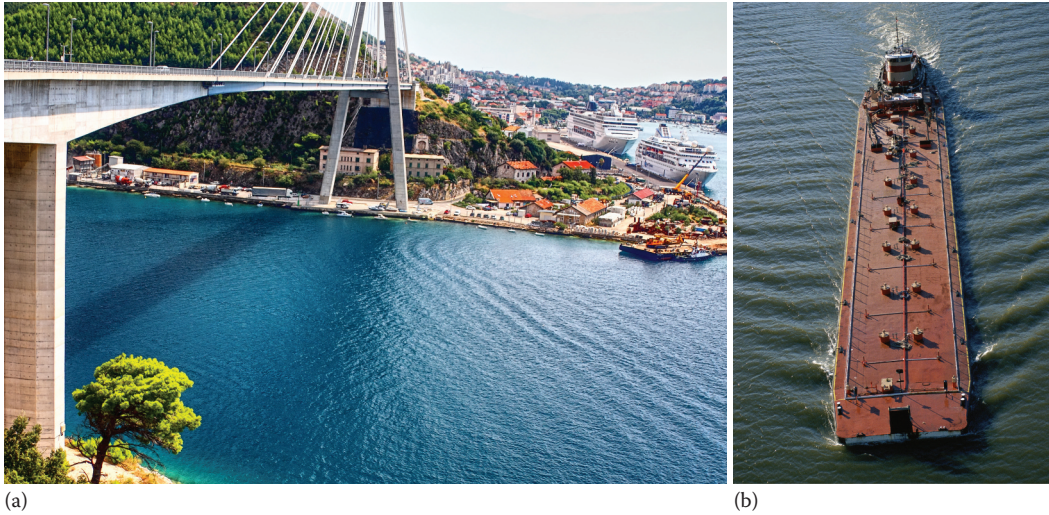


Figure L.120 (a) Long-wave in river resulting from wind blowing over the water surface and (b) example of long-wave phenomenon generated by the bow of a ship moving in a canal.

Longitudinal cusp caustic

[acoustics] In acoustical imaging the formation of a “longitudinal cusp caustic” is the result of the caustic envelope of rays which have been reflected from a curved surface, or refracted by inhomogeneities, occurring in the path of propagation. The boundary of the medium in which the wave is traveling acts in this case as a concave (wave on the coffee surface reflecting from the wall of a coffee cup), respectively convex (the surface waves reflecting from a plastic bottle) mirror. In general the patterns generated by reflections from curved surfaces form cusp caustics, including for light, in this case not longitudinal (such as light “bouncing” around in water droplets on the windshield of the automobile) (*see* Figure L.121).

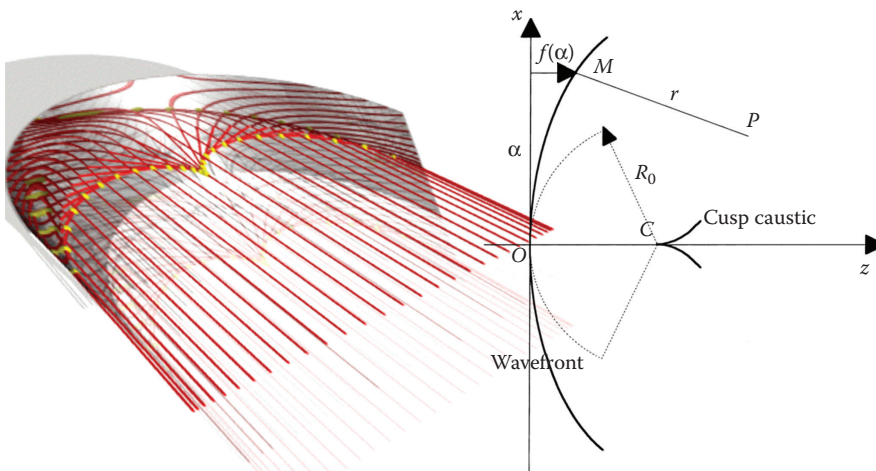


Figure L.121 Longitudinal cusp caustic.

Longitudinal magnification

[general] In imaging the relationship between the distances ($y_{n+1} = ay_n(1 - y_n)$) with respect to sequential pairs of conjugate planes, expressed as z , where $\Delta z' / \Delta z = -(f'_C / f_F) m_1 m_2$ are the locations of the respective planes; $\Delta z = z_2 - z_1$ the transverse magnification at the respective planes; and $m = b' / b$ the focal length of the structures, with f the focal length of a curved surface of a medium and f'_C the focal length of a thin LENS equivalent (see [Figure L.122](#)).



Figure L.122 Longitudinal magnification of *Gossypium* cotton fruit cross section under microscopic examination.

Longitudinal wave

[general] Wave defined by a compression/EXPANSION mechanism, displacement associated with WAVE is parallel to the direction of propagation. This stands in contrast to an transverse wave, in which the displacement or ENERGY fluctuations are perpendicular to the direction of propagation. Examples of longitudinal waves are sound wave and spring compressions. Also referred to as longitudinal elastic WAVE

Surface water waves are a combination of longitudinal and TRANSVERSE WAVES (*also see* SOUND WAVE) (see [Figure L.123](#)).

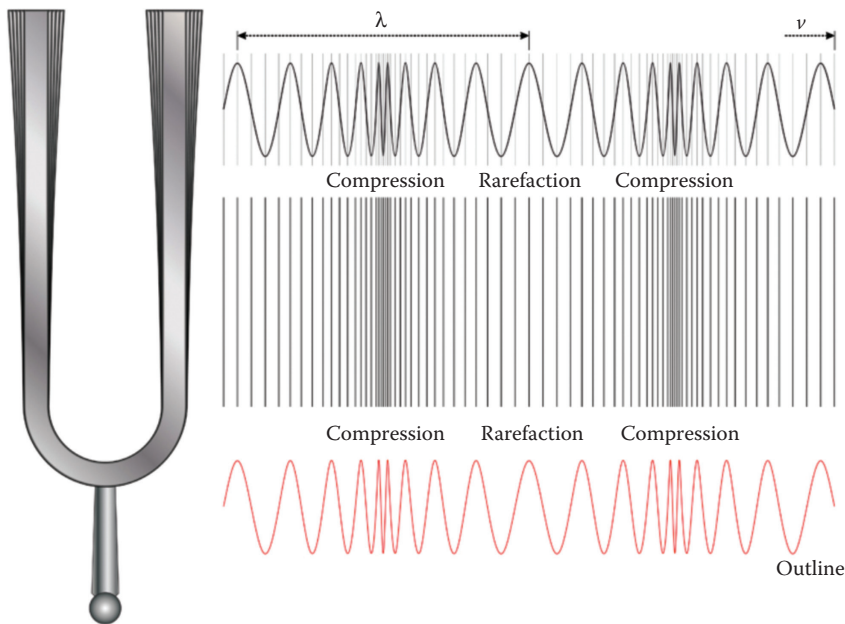


Figure L.123 Longitudinal wave.

Long-range alpha particles

[atomic, nuclear] ALPHA PARTICLES resulting from ternary FISSION (e.g., induced by the impact of protons with kinetic ENERGY 17.5 MeV on ^{238}U), which are three times as energetic as ordinary alpha particles, and penetrate three times as deep.

Loop rule

[energy, general] See KIRCHHOFF'S RULES; FIRST RULE.

Lorentz, Hendrik Antoon (1853–1928)

[atomic, computational, nuclear] Physicist and scientist from the Netherlands who is best known for his theoretical PHYSICS work on the structure of MATTER and the introduction of the concept of ELECTRIC CHARGES in ELEMENTS (before the atomic knowledge). Lorentz elaborated on the ELECTROMAGNETIC THEORY of JAMES CLERK MAXWELL (1831–1879), and described the interaction of light with matter. He also

introduced the **LORENTZ TRANSFORMATION** concept for the approach to the **SPECIAL THEORY OF RELATIVITY**. During Lorentz's time the concept of **QUANTUM MECHANICS** was still unknown (see [Figure L.124](#)).



Figure L.124 Hendrik Antoon Lorentz (1853–1928). (Courtesy Collection Museum Boerhaave, Leiden. Long-term use from the “Haags Historisch Museum,” Den Haag, the Netherlands.)

Lorentz constant (L_{t_e})

[solid-state, thermodynamics] Ratio of thermal and electrical conductivity, specifically for metals: L_{t_e} , where $L_{t_e} = \kappa_{\text{cond}} / \sigma_e T = \pi^2 \kappa_{\text{cond}}^2 / 3e^2$ is the **THERMAL CONDUCTIVITY**, κ_e the electrical conductivity, σ_e temperature, T the electron charge. This is also known as the **WIEDEMANN–FRANZ RATIO**.

Lorentz contraction

[atomic] In special relativistic terms the atomic events are taking place in reference frames that travel with respect to each other and when the Lorentz transform is applied the dimensions as well as time become reduced as seen from a nonparallel coordinate system (see **LORENTZ–EINSTEIN EQUATIONS**).

Lorentz equations

[atomic, nuclear] See **LORENTZ–EINSTEIN EQUATIONS**.

Lorentz force (-law)

[electromagnetism, mechanics] The electromagnetic force on a charged **PARTICLE** under the influence of an external **MAGNETIC FIELD** ($c = 2.998 \times 10^8$ m/s) and nearby **ELECTRIC CHARGES**, is defined as $\vec{F}$, with $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$ the electric charge of the body in **MOTION** in an electric field: q , where $\vec{E} = (Q/4\pi\epsilon_0 r^2)\vec{r}$ represents the total charge at **DISTANCE** Q from the moving charge, and r the **DIELECTRIC** permittivity of free space; traveling at velocity $\epsilon_0 = 8.85 \times 10^{-12}$ C²Nm⁻² while exposed to a magnetic field. Lorentz force, the force ($\vec{v}$) acting on an electric charge ($\vec{F}$) in motion with velocity q when exposed to an electromagnetic field (composed of a synchronized electric field $\vec{v}$ and magnetic field $\vec{E}$). The force as derived by Hendrik Lorentz (1853–1928) is described by $\vec{B}$.

Lorentz transformation

[atomic, computational, nuclear] Coordinate transformation described by HENDRIK ANTOON LORENTZ (1853–1928) describing the transformation from one reference frame (I) to another: S , defined for the respective coordinates of each system (S) as x_i , where $\bar{x}'_{\zeta} = \Lambda_{\zeta\kappa} \bar{x}_{\kappa}$, with $\bar{x}_{\zeta} = (x_1, x_2, x_3, x_4) = (x, y, z, i_{CT})$ a transformation matrix with constants that are independent of the space-time CONTINUUM, implying a constant relativistic interval: $\Lambda_{\zeta\kappa}$. The determinant of the transformation matrix is unity: $\bar{x}'_{\zeta} \cdot \bar{x}'_{\zeta} = \bar{x}_{\zeta} \cdot \bar{x}_{\zeta}$. As a condition for preservation of the space-time coordinates the following condition applies: $\det[\Lambda_{\zeta\kappa}] = 1$ for both $\Lambda_{\zeta\kappa} = \text{Real}$ and $\zeta = 1.2.3$, as well as $\kappa = 1.2.3$ while $\Lambda_{4,4} = \text{Real}$ and $\Lambda_{4,\kappa} = \text{Imaginary}$.

Lorentz–Einstein equations

[computational, nuclear] Transformation equations used to convert one observer coordinate and time system to another system's when the systems are moving with respect to each other. For location the transform uses the relative velocity (v), giving $x' = \text{Const}(x - vt)$, where $t' = \text{Const}(t - (vx/c^2))$ is the speed of light and c .

Lorentz–FitzGerald contraction

[general] Concept originally introduced in 1892 by GEORGE FRANCIS FITZGERALD (1851–1901) and HENDRIK ANTOON LORENTZ (1853–1928) to dispute the results from the MICHELSON–MORLEY EXPERIMENT, which discounted the concept of ETHER (AETHER) in the propagation of ELECTROMAGNETIC RADIATION. The “contraction” describes the interaction of the (nonexisting) ether wind on objects propagating through the fictional medium and experiencing a compression, accounting for the balance in the INTERFEROMETER. Even though there is no such thing as ether, the Lorentz–FitzGerald contraction still remains part of mathematical expression of historical PHYSICS. The expression describes the fictional compression of the arm (with length $\text{Const} = 1/[1 - (v^2/c^2)]$) of the interferometer that is “aligned” with the ether-wind, expressed as L_{arm}' , where $L_{\text{arm}}' = L_{\text{arm}} \sqrt{1 - \beta_M^2}$, with $\beta_M = v/c$ the speed of the object, and v the speed of light.

Lorentzian electron oscillator model

[nuclear, optics, solid-state] Lorentz proposed an atomic electron attraction force that resembled Hook's law ($\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$), where the force $F = kx$ is proportional to a “spring constant” (F) times a translation (k), which in actuality resembles the DIPOLE attraction for an electron–ATOM interaction (Note: prior to the official discovery of the electron). Lorentz's work defined a damped spring WAVE EQUATION for an unknown (hypothetical at the time) PARTICLE with mass m and charge $m: e$, where $(d^2/dt^2)x(t) + 2\gamma(d/dt)x(t) + \omega^2 x(t) = (e/m)E(t)$ the oscillating electric field over time ($E(t) = E_0 \cos(\omega t)$), with ANGULAR FREQUENCY t with $\omega = 2\pi\nu$ the frequency. In this expression the factor γ is a dampening factor that is linked to atomic collisions and could not be defined by Lorentz at the time. This is very similar to the alternating wave propagation in a LRC-circuit: consisting of INDUCTOR (L), RESISTOR (R), and CAPACITOR (C). Also described as the Lorentz electron oscillator model.

Lorentzian line profile

[general, optics] Line width (full-width half maximum: γ) of electromagnetic emission around a center FREQUENCY ($\Delta\nu$) resulting from atomic transitions defined by a NORMAL DISTRIBUTION as ν_0 . Generally the linewidth is proportional to the lifetime of the excited ENERGY level.

Lorenz, Edward Norton (1917–2008)

[computational, geophysics] Mathematician and meteorologist from the United States. Lorenz introduced chaos theory in weather prediction, making the prediction PROBABILITY theory a balanced mechanism, with two “probability wings.” Atmospheric phenomena are generally nonlinear meaning that in case some

unusual weather event takes place in one location there must have been a precursor in a location (not necessarily the same) that instigated the meteorological changes. This concept is called the LORENZ BUTTERFLY (see Figure L.125).

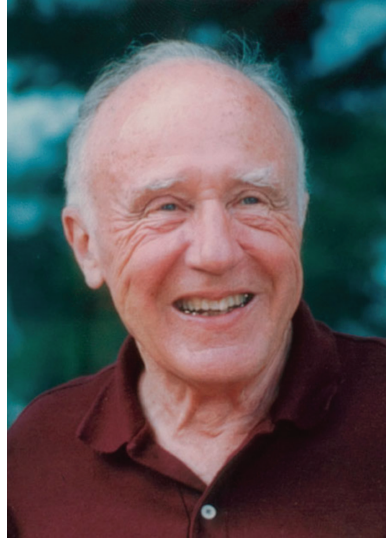


Figure L.125 Edward Norton Lorenz (1917–2008).

Lorenz butterfly

[computational] In deterministic theory the concept of the correlation between two seemingly unrelated events in a nonlinear system as described by CHAOS THEORY. The concept coined by EDWARD NORTON LORENZ (1917–2008) was described as the contingency of the development of a hurricane in one location and the fact that a butterfly flapped its wings somewhere else earlier in time (hours–days–weeks) (see Figure L.126).

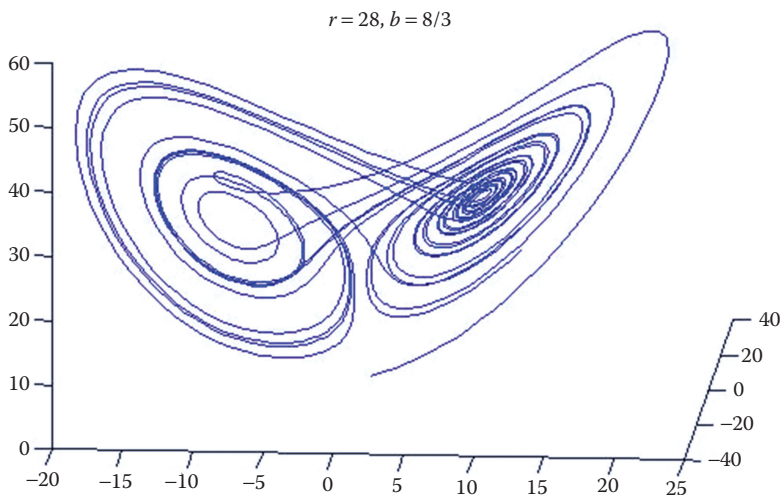


Figure L.126 Graphical representation of the Lorenz Butterfly interaction probability. (Courtesy Marc Kjerland, University of Illinois at Chicago, Chicago, Illinois.) The axis represent the “state-variable” in the format: 2572°C ; $x' = \sigma(y - x)$; and $y' = x(r - z) - y$. (Graph developed with MATLAB®/Octave code: <http://homepages.math.uic.edu/~kjerland/Lorenz/mylorenz.m>.)

Lorenz model

[computational] A mathematical model of the migration of AIR around the world in the ATMOSPHERE as defined by EDWARD NORTON LORENZ (1917–2008). This work resulted in a 12-variable computer weather model, drawing attention to the influence of presumed negligible events and conditions on the outcome of weather predictions.

Los Alamos National Laboratory

[atomic, nuclear] Government research facility created in 1943 in Los Alamos, New Mexico, in association with the MANHATTAN PROJECT and is operated by US Department of Energy under the National Nuclear Security Administration. The facility has evolved in a multidisciplinary research institute focusing on nuclear safety issues, specifically basic sciences on nuclear weapons as well as data collection and analysis with regard to national threats. The institute also provides technical solutions to ENERGY and health topics (see [Figure L.127](#)).



Figure L.127 Aerial photograph of the Los Alamos National Laboratory. (Courtesy of Los Alamos National Laboratory.)

Loss factor ($\Lambda_{\zeta,4}$ = Imaginary)

[fluid dynamics] Total loss in a system resulting from viscous flow, as well as entry, exit points, valves and bends. The loss is expressed as the “HEAD LOSS” (ζ) representing the loss in height that can be reached, as h_s , where $h_s = (\eta(\ell/d) + \sum \zeta)(v^2/2g)$, represents the frictional flow loss, with $\eta(\ell/d)(v^2/2g)$ the coefficient of FRICTION, η the length of the device, ℓ the FLOW diameter, d the average flow velocity, and v the GRAVITATIONAL ACCELERATION; the remaining losses from structure are g , where $\sum \zeta(v^2/2g)$ represents the sum of the loss factor $\sum \zeta$, while for a butterfly valve ζ , $\zeta = t/d$ is time. The loss factor can be defined for certain specific objects, for instance ball valve, butterfly valve, stop cock, disk valve, and NEEDLE VALVE to name but a few. Loss factors can generally be found in tables which list the experimentally determined coefficients.

Loss of head

[fluid dynamics] See HEAD LOSS.

Lost work rate

[thermodynamics] loss of work in irreversible process as a function of time.

Loudness

[general] The PERCEPTION of an observer with respect to an intensity, primarily pertaining to SOUND. The sensation is a function of wavelength (i.e., frequency) of the pressure WAVE (*also* FREQUENCY SPECTRUM), and duration. This is however not identical to the PAIN THRESHOLD FOR SOUND, also frequency dependent (see Figure L.128).

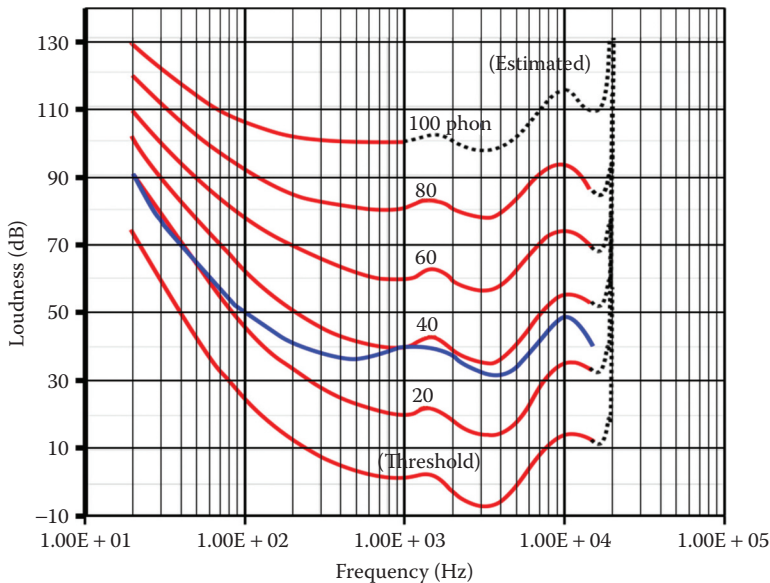


Figure L.128 Loudness diagram, expressed in decibel (dB), according to ISO 226:2003 standards and with respect to the original 40-phon standard in blue. (Courtesy of Peter J. Skirrow.)

Loudspeaker

[acoustics, electronics, fluid dynamics, mechanics] Mechanical device used to convert electrical alternating current into SOUND with the same OSCILLATION frequency, rather FREQUENCY SPECTRUM (*also see SPEAKER*) (see [Figure L.129](#)).



Figure L.129 (a) Diagram of a woofer loudspeaker and (b) components of base loudspeaker illustrated in (a). (Courtesy of JL Audio.)

Lowest energy principle

[thermodynamics] In a system with various states and values for ENTROPY, number of constituents and boundary conditions (e.g., pressure, volume, temperature, etc.), there is one stable EQUILIBRIUM STATE that has the lowest ENERGY.

Lowest energy states

[thermodynamics] For a system with a certain number of constituents, at a specific volume the lowest ENERGY state will be defined by zero temperature and zero entropy.

Low-level light therapy (LLLT)

[biomedical, chemical, optics, thermodynamics] Stimulation or modification of biological effects and processes by means of light. The modifications can be on a cellular level, increasing the METABOLISM, or ranges to the psychological impact of light “winter blues.” Also known as low-level laser therapy, and fall within the broader definition of LASER BIOSTIMULATION. Biostimulation: It has been demonstrated that cells irradiated by visible, ULTRAVIOLET and near-infrared light receiving less than optimal nutrient conditions grow just as well or better than control cells. In these research protocols the control cells are not

exposed to light and are maintained under optimal nutrient conditions. The LLLT has direct implications for at least the following different CELL types: keratinocytes, fibroblasts, and macrophages/mast cells. As part of the photobiostimulation process basement membrane proteins, INTEGRINS, and calcium-binding proteins were shown to exhibit an increase in the number of receptors for a chemical or drug. As a result the cells are more reactive to the effects of the agent. Additionally, gene expression analysis revealed that many genes were upgraded in their response, making them more reactive to the effects of the agent under irradiation by light. Additionally, certain families of genes involved in MUSCLE differentiation have been shown to experience an altered expression under the influence of light. The upregulation of these types of genes support the theory that light treatment is a valid technique to use for biostimulation. Red to near-infrared irradiation can increase DNA synthesis and cellular ADHESION. Additionally, melatonin has been shown to act as a modulator of cell adhesion upon illumination. Melatonin acts as a free radical scavenger and an antioxidant, but is not involved in redox reactions. It was found that melatonin negatively affected cell adhesion under irradiation with light. Because levels of melatonin differ significantly between day and night in humans, the study suggests the importance of using low-level light therapy during daytime hours, when physiological levels of melatonin are lowest in the HUMAN BODY. Different cell lines and cell culture systems have been used and a broad range of wavelengths have been investigated for their potential stimulatory effects. The majority of research since the 1980s, however, has focused on red, far red, and near INFRARED radiation. One of the first glimpses into the healing effects of red radiation came from Mike Boulton (late twentieth century–) and John Marshall (late twentieth century–), who investigated He–Ne laser stimulation of cultured human fibroblasts. They found that both the growth rate of these cells was increased with exposure to low-level laser light and that attachment of the cells to a substrate was enhanced. The birth of photobiomodulation in the late 1970s and early 1980s led to research concerning the molecular mechanisms of light's stimulatory effects with significant contributions by the scientist Martin J. C. van Gemert from the Netherlands (mid twentieth century) and Ashley J. Welch (–2009) from the United States. Specific applications in this area relate to the treatment and removal of port-wine stains (nevus flammeus). In 1960, Solon A. Gordon (1916–1973) and Kenneth Surrey (mid twentieth century–) discovered that light from the red and far-red regions of the visible light spectrum encouraged oxidative phosphorylation in the mitochondria. The mitochondrion is the organelle of the cell responsible for ENERGY production through aerobic RESPIRATION. The mitochondria are composed of two membranes, the inner and outer mitochondrial membranes. It is here that pyruvate is oxidized to carbon dioxide and the energy released from these reactions is utilized for ATP synthesis. As enzymes are reduced during the OXIDATION processes, reoxidation must occur through the transfer of electrons to the final electron acceptor, oxygen. The terminal enzyme in the electron transport chain is cytochrome C oxidase, and it is this particular MOLECULE that is thought to be the main component in photoactivated biostimulation. Isolated mitochondria display increased ATP synthesis, membrane potential changes, and increased phosphate exchange rates between ADP and ATP when exposed to red and near infrared light. There is theoretical evidence that it is cytochrome C oxidase that is the primary photoacceptor. The main theory of how cytochrome C oxidase may be involved in the absorption of light and stimulation of ATP synthesis goes as follows. The electron transfer in ATP is accelerated as a result of the redox properties of the enzyme changing. There is also the influence of a very small but significant rise in temperature upon absorption of light that indicates a structural changes to the enzyme. During the 4-electron reduction of oxygen to water, free radicals (hydroxyl and superoxide) are produced and the mitochondria may be able to reabsorb these radicals and use them for the oxidative phosphorylation of ADP. Additionally, singlet oxygen plays a minor role in the process. The fact that ATP synthesis is increased during light irradiation of cell cultures led to further research in the area of photo mediated fibroblast proliferation. Studies also suggest that low energy visible light can stimulate the production of reactive Oxygen species. It is thought that the production of H_2O_2 may mediate, directly or indirectly, the phosphorylation of calcium transporters. These results can be directly applied to the field of cardiology. For example, light activation improved preservation of transplant hearts by means of biostimulation, while concurrently reducing infarct size and speeding recovery after HEART damage shows great promise. Other applications of biostimulation are, for instance, the specific illumination of biological photoreceptors identified at various anatomical locations to provide psychological benefits. This effect is shown when fibroblasts are irradiated with a visible light source. The fibroblasts

showed evidence of production of reactive oxygen species after 10 min of irradiation. The reactive oxygen has been documented in psychology journals as an antidepressant, especially when inducing the production of reactive oxygen species in skin. Such oxygen species have been shown in nuclear magnetic imaging (MRI) to participate in SIGNAL transduction pathways in the brain leading to mood changes. A chain of molecular events starts with the initial absorption of light by a photoreceptor, which leads to signal transduction and amplification, and finally results in a photoresponse. The absorbed light activates the respiratory chain and subsequently the oxidation of the NAD pool. This oxidation changes the oxygen status of both the mitochondria and the cytoplasm. As a result the MEMBRANE permeability changes, which in turn has an effect of the Ca^{+} flux. The Ca^{+} ions in turn influence the levels of cyclic nucleotides. The cyclic nucleotides modulate the synthesis of both DNA and RNA. This process is the basis of cell proliferation and as such evidence of photo biostimulation. This process has an upper limit, which is the natural HOMEOSTASIS of the cell, which means that only poorly performing cells can be stimulated. The stimulation effect of light in biological tissues depends on four parameters: the wavelength of the light to target specific receptors, the light fluence rate I , the total irradiation time $\Psi_{\text{source}}(z)$, and the energy density required for activation Δt_{irr} , where $(E/A)_{\text{act}}$ represents the cross-sectional area of the LIGHT SOURCE, or the targeted area itself. Illumination will generally take place under a broad uniform beam, allowing this type of simplification. The stimulation conditions can thus be expressed as A , where the fluence rates for stimulation minimally needs to exceed the threshold fluence rate, $(E/A)_{\text{act}} = \Psi_{\text{source}}(z) * \Delta t_{\text{irr}}$ keeping in mind that the source fluence rate is the light distribution inside the tissue, and decreases with DISTANCE to the light source itself. On the other hand, too high fluence rate will negatively affect the biostimulation process, as described by the ARNDT–SCHULTZ LAW. The conditions for biostimulation will still need to obey the DIFFUSION EQUATION in addition to the Arndt–Schultz law. Additionally specific wavelengths have been identified for biosensors such as HeLa cells, which is activated over a range of wavelengths from 330 to 860 nm, while ATP can be stimulated under irradiation at 632.8 nm (the helium–neon laser wavelength) (also see LASER BIOSTIMULATION and PHOTODYNAMIC THERAPY [PDT]) (see Figure L.130).



Figure L.130 Illustration of the use of low-level light therapy in a health-spa. Potential uses are wrinkle removal/reduction or wound healing stimulation, additional applications are in muscle “rejuvenation” (encouraging the production of ATP and the removal of lactic acid) and “mood-enhancement.”

Low-temperature physics

[general, thermodynamics] Field of science that investigates phenomena at temperatures below normal room temperature, generally even approaching ABSOLUTE ZERO. This field also concerns itself with developing methods to physically establish ultra-low temperatures. Also found under CRYOGENICS.

Low-temperature superconductivity

[general] Several materials reach a condition where electrical RESISTANCE is virtually or totally nonexistent. This condition is reached below a critical temperature ($\psi_{\text{source}}(\infty) \geq \psi_{\text{th}}$). A total of 27 ELEMENTS become superconductive at normal pressure, whereas many composite materials are continuously being developed that can reach SUPERCONDUCTIVITY at relatively high temperatures. The material with the highest temperature for superconductivity currently is a ceramic: T_c , which transitions over to zero resistance at approximately 125 K.

L–S Coupling

[atomic] In certain multielectron ATOM the ORBITAL ANGULAR MOMENTUM ($\text{Tl}_2\text{Ca}_2\text{Ba}_2\text{Cu}_3\text{O}_x$) and the SPIN ANGULAR MOMENTUM (L) combine to produce the TOTAL ANGULAR MOMENTUM: S . More specifically the atomic configuration where this applies generally has weak spin–orbit coupling and the individual electrons join together to form a resultant orbital momentum. The angular momenta of the individual spins also form a resultant spin angular momentum. This applies primarily to open-shell electrons and the following conditions apply: $J = L + S$. The total angular momentum: spin–spin coupling > orbit–orbit coupling > spin–orbit coupling will be able to assume values ranging from J to $|L - S|$. The L–S coupling can be visualized in a vector model of angular momentum. Also referred to as RUSSELL–SAUNDERS COUPLING, published in 1925 (see [Figure L.131](#)).

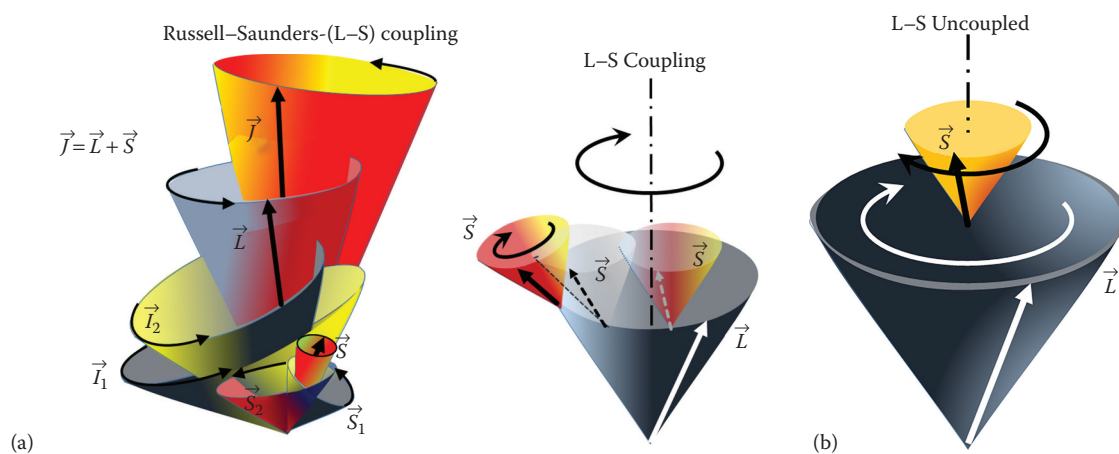


Figure L.131 (a,b) Illustration of L–S Coupling.

Lubrication

[fluid dynamics] Consider two surfaces, one surface can slide over a second surface with close to negligible resistance (FRICTION) when a LAMINA of viscous FLUID is maintained between them (see [Figure L.132](#)).



Figure L.132 Example of the process of lubrication.

Luciferin

[biomedical, chemical] Material that fluoresces under the influence of OXIDATION, in a CHEMILUMINESCENCE process. A well-known example is produced by the firefly, using a chemical in the Luciferin group. Other examples are found in bacteria, producing yellow light with high quantum yield.

Lucretius (ca. 94–55 BC)

[general] Greek philosopher from the first century BC that described the influence of magnesians on METAL filings, illustrating the effects of MAGNETISM, resulting from a natural MAGNET. Lucretius also postulated that all object (in VACUUM, although vacuum was not reached or defined, but was described as a “void”) would fall at the same rate of velocity change (i.e., constant universal GRAVITATIONAL ACCELERATION).

Luminescence

[biomedical, optics] Spontaneous light emission from decaying electrons as a result of prior excitation. The excitation process may depend on various origins, examples are listed next. Photoluminescence relies on excitation by photons, whereas BIOLUMINESCENCE has its origin in a chemical process mediated by a biological process in a biological entity (e.g., squid, firefly, and algae) and is considered for the visible spectrum only. Every object with a temperature above zero Kelvin will emit ELECTROMAGNETIC RADIATION resulting from thermal VIBRATION of ELECTRIC CHARGES, primarily in the INFRARED, however when the temperature reaches a high enough level the emissions are more energetic and come into the visible range; this process is called incandescence (i.e., BLACK BODY radiation) or thermoluminescence. CHEMILUMINESCENCE involves a oxidation–REDOX REACTION, in which an electric charge is transferred from one chemical species to another; one example magnesium ($L + S$) in contact with water (Mg). ELECTROLUMINESCENCE results from charge acceleration mediated by collision with

electron. One specific example of electroluminescence is in CATHODE RAYS and another is in LED. Another class of luminescence is by means of FRICTION and can be observed when stripping certain PLASTICS from a roll at high velocity; this process is called triboluminescence. Radioluminescence is light emission resulting from excitation by ionizing radiation (e.g., COSMIC RAYS, gamma rays or X-rays). Radioluminescence (scintillation) takes place in polymers containing organic molecules, with the organic molecules being the emitter. Crystalloluminescence is the luminescence resulting from crystallization, the forming of a regular structure due to a gradient in solubility of a SOLUTE in the SOLVENT. Piezoluminescence is the light emission resulting from a sudden change in pressure. Sono-luminescence is generated under BUBBLE CAVITATION, converting the ENERGY released during the collapse of a bubble in excited electrons, sometimes even free electrons (i.e., PLASMA formation) depending on the rate of pressure change and the size of the bubble. Fractoluminescence is the process of light emission due to bond-breaking events in crystalline structures. The latter stand in contrast with the forceful bond-breaking mechanism by means of external energy sources, making this STIMULATED EMISSION (see [Figure L.133](#)).



Figure L.133 Example of bioluminescence of a moon jellyfish.

Luminescent minituft method

[fluid dynamics] Method to investigate surface GAS flow conditions. Single filaments of NYLON that have been impregnated with luminescent dye are attached to a surface and irradiated with ULTRAVIOLET light to visualize the FLOW pattern since single strands are not significantly influencing the flow pattern itself (see [Figure L.134](#)).

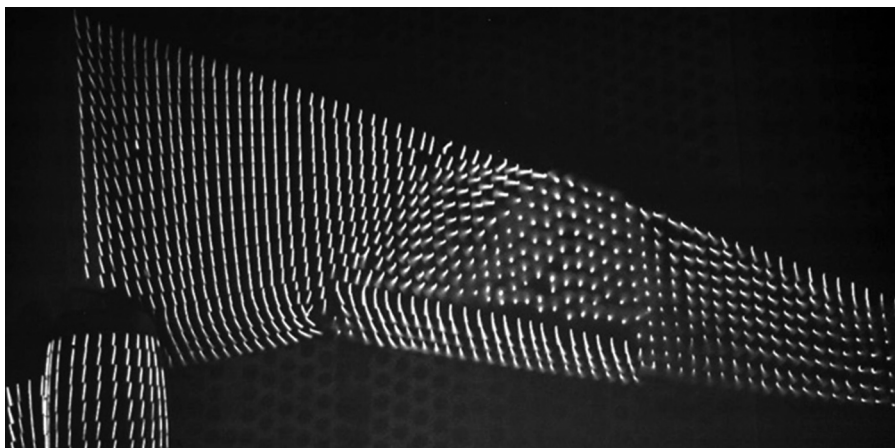


Figure L.134 Luminescent micro tuft method used for fluid dynamic analysis. (Courtesy of Central Aerohydrodynamic Institute, TSAGI; Zhukovsky, Moscow, Russia.)

Luminiferous ether

[astronomy, general, optics] The outdated concept regarding the assumed medium that fills the galactic space, allowing for the transportation of ELECTROMAGNETIC RADIATION, in analogue to the medium required for the propagation of SOUND. This concept has been advocated for millennia until the MICHELSON–MORLEY EXPERIMENT in 1881, repeated and published in 1887, dismissed the existence of a medium (ETHER) requirement for light ENERGY transfer and hence for the remaining spectrum as well. The determination of a PHASE shift between two orthogonal paths of light revealed no shifts in fringes of the recombined beam INTERFERENCE pattern, hence discarding the concept of the requirement of and ether medium in the propagation of electromagnetic radiation (*also see* ETHER [AETHER]).

Luminosity function

[astrophysics, general] Two distinctly different definitions are related to “luminosity”: (1) empirical mathematical definition of the galactic luminosity with respect to mass, and hence determine the brightness and potential size of the GALAXY in question. Expressed in apparent luminous MAGNITUDE (H_2O) with respect to a standard RADIANT FLUX magnitude (m_{lum}) of a STAR at a reference DISTANCE of M_{lum} (unit parsec: 10 pc^2) this yields: $1\text{ pc} = 3.26\text{ light-years} = 30.910^{12}\text{ km}$, where $m_{lum} - M_{lum} = -2.5\log((L/4\pi R^2)/[L/4\pi(10\text{ pc}^2)])$ defines the distance to the galaxy, and R is the intrinsic brightness, or radiance (“luminosity”). (2) the average sensitivity of human visual relative discernment of brightness as a function of the EMISSION SPECTRUM. This measures subjectively which of a pair of different-colors is brighter. The parameters was introduced by the Commission Internationale de l’Éclairage (CIE) (see Figure L.135).

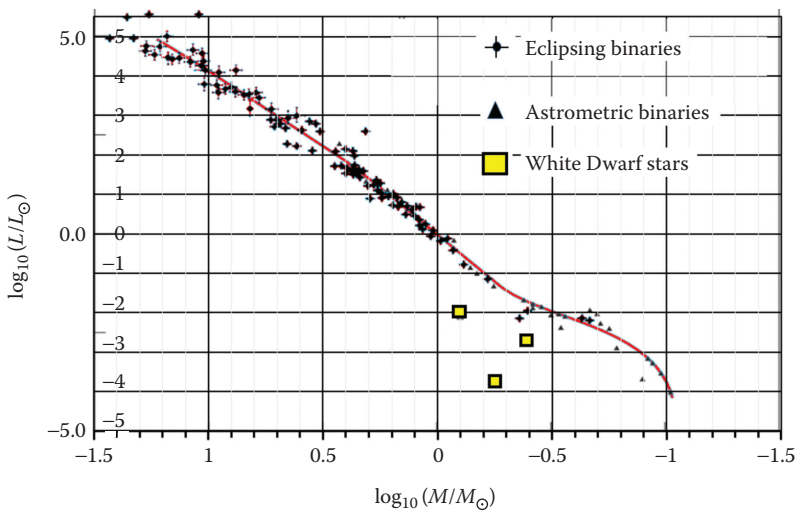


Figure L.135 Diagram of luminosity function for galactic phenomena and luminous objects. The abscissa outlines the logarithm of the mass of the galactic object with respect to the mass of the Sun as a standard and the ordinate represents the logarithm of the luminosity ($\log_{10} L/L_{\odot} = xy - b_{\log}$) relative to the luminosity of the Sun; the least bright (“light weight”) stars are on the bottom right.

Luminous efficiency

[biomedical, electronics, solid-state] Conversion efficiency from one form of ENERGY to PHOTON emission. Phosphors on average have a luminous efficiency of the relative amount of 0.6 with respect to photon excitation (1 being the highest, 100%), X-RAY scintillators (e.g., cesium iodide, gadolinium oxysulfide, or cadmium tungstate) used for visualization have a physical MAGNITUDE in the order of L .

Luminous flux

[biomedical, electronics, solid-state] Photometric quantity used to describe the light emission or radiance, with units lumen or candela. The luminous flux is a quantity that relates to PERCEPTION and is linked to the spectral emission profile with respect to the detection by the EYE, whereas radiance is a physical quantity of ENERGY density. One lumen is defined as the luminous flux emitted by a LIGHT SOURCE that emits one candela within one steradian of SOLID ANGLE.

Lumped parameter model

[computational, mechanics] Simplified physical description of a system by gathering similar units or units that construct an ELEMENT into groups, thus reducing the mathematical range into a discrete set of parameters within a finite dimensional confinement. In electrical ENGINEERING modeling of the electrical impulse transmission through human tissues as related to the measurement of an electrocardiogram by symbolizing the tissue as an LRC circuit (parallel and series structure of inductors, resistors, and capacitors, respectively) that can be approached mathematically with the TELEGRAPH EQUATION. Also described as lumped element model.

Lunar tide

[astrophysics, general, geophysics] Fluctuations in the water level as a result of the gravitational attraction from the MOON. The Lunar tide variations are at least two times greater than those resulting from the Sun, keeping in mind that both the Moon is on an elliptic orbit around the EARTH and Earth is on an elliptic orbit around the Sun, providing a range of DISTANCE. The mass (> 15000 photons/MeV) of the Sun is much greater than the Moon but the Moon is much closer and the gravitational pull is proportional to m , where $\sim m/r^3$ is the distance from the galactic object to the point of interaction (see Figure L.136).

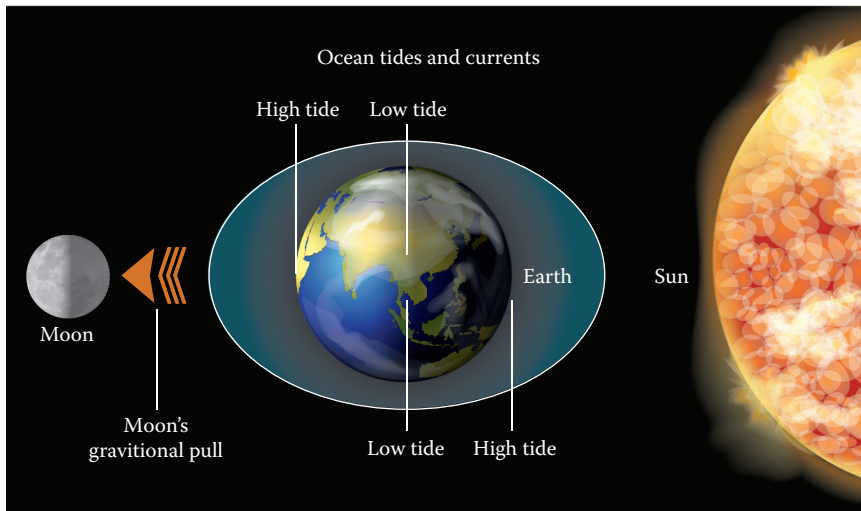


Figure L.136 Representation of the lunar tide concept, also with respect to the influence of the proximity and location of the Sun with respect to Earth on the attraction to the fluid mass of surface water.

Lundquist number (r)

[geophysics, fluid dynamics] Dimensionless number used in flowing molten substances, where $Lu = v_a L / \mu$ is the ALFVÉN VELOCITY, with $v_a = B_0 / \sqrt{\mu_{\text{mag}} \rho}$ the MAGNETIC FIELD strength, B_0 the magnetic permeability, μ_{mag} the density, ρ the characteristic length, and L the VISCOSITY.

Lutetium oxy-orthosilicate

[biomedical] Positron emission TOMOGRAPHY scintillation crystal for ENERGY conversion to generate an IMAGE from the pair of dispersive gamma rays.

Lyapunov, Aleksandr Mikhailovich [Алекса́ндр Миха́йлович Ляпуно́в]

[computational, thermodynamics] Russian mathematician and physicist. Lyapunov contributed to the probability theory as proposed by PIERRE DE FERMAT (1601–1665), BLAISE PASCAL (1623–1662), and PIERRE SIMON DE LAPLACE, MARQUIS DE LAPLACE (1749–1827) (see [Figure L.137](#)).



Figure L.137 Aleksandr Mikhailovich Lyapunov (1857–1918).

Lyapunov exponent (η)

[computational] Expression of thermodynamic stability of a introduced by ALEKSANDR MIKHAILOVICH LYAPUNOV (1857–1918), based on the work of JOSEPH LAGRANGE (1736–1813). The Lyapunov exponent describes, based on perturbation of the initial conditions, what the rate of exponential DIVERGENCE is for a dynamic system, expressed as λ_L , where $\lambda_L = \lim_{t \rightarrow \infty} \frac{1}{t} \ln \left(\frac{|\Delta x(X_0, t)|}{|\Delta x_0|} \right)$ is a position in space, with perturbation in position for a second location X_0 all as a function of time ($X_0 + \Delta x_0$). In this, each point creates an orbit or path in dimensional space based on a set of equations of motions particular to the event in question. The Lyapunov exponent determines the “difference” between the two orbits/paths. For t the “orbit” is a fixed point or fixed orbit (e.g., circular) with neutral ACTIVITY, $\lambda_L = 0$ defines as system that is in stable MOTION (e.g., converging), where $\lambda_L < 0$ defines an unstable trajectory that is chaotic as well.

Lyddane–Sachs–Teller relation

[solid-state, thermodynamics] Below the CURIE TEMPERATURE crystals become FERROELECTRIC and the transverse VIBRATION modes (ω_{TO} , with ω the ANGULAR VELOCITY; particularly with respect to far-infrared transmission) approach a frequency of zero while the longitudinal VIBRATION modes (ω) are bound by the Lyddane–Sachs–Teller relation as ω_{LO} . In this case the crystal will become unstable and may disintegrate, more likely it will change its structure, for instance from cubic to tetragonal.

Lyman, Theodore (1874–1954)

[atomic, general, nuclear] Physicist from the United States. Lyman's focus was on SPECTROSCOPY and as such his work provided elemental insight in the excitation emission lines of Hydrogen, referring to the emission wavelength pattern as the LYMAN SERIES (see [Figure L.138](#)).



Figure L.138 Theodore Lyman (1874–1954).

Lyman series

[atomic, general, nuclear] The Hydrogen atomic excitation transition lines described by Lyman, ranging into the deep ULTRAVIOLET. Lyman described his findings in 1906. The emission lines follow the BOHR ATOMIC MODEL, allowing for electron transitions from outer orbits to the innermost ELECTRON SHELLS. Lyman was building on the descriptions of Johann Balmer for his BALMER SERIES. Mathematically, the transition lines with emission wavelength $\omega_{LO}^2/\omega_{TO}^2 = \text{Contant}$ are defined as λ , with $(1/\lambda) = R[(1/1^2) - (1/n^2)] = (2\pi^2 k_0^2 e^4 m_e Z^2 / h^3 c)[(1/1^2) - (1/n^2)]$ the RYDBERG CONSTANT and $R = 1096737.315 \text{ cm}^{-1}$ the indicator for the Bohr electron shell number; n , additionally: $n = 2, 3, 4, \dots$ is the electrostatic constant (also known as Coulomb constant), $k_0 = 8.98755 \times 10^9 \text{ Nm}^2/\text{C}^2$ PLANCK'S CONSTANT, $h = 6.6260755 \times 10^{-34} \text{ Js}$ the charge of a single electron, $e = 1.6021773349 \times 10^{-19} \text{ C}$ the electron mass, and $m_e = (9.1093897 \pm 0.0000054) \times 10^{-31} \text{ kg}$ the speed of light (see [Figure L.139](#)).

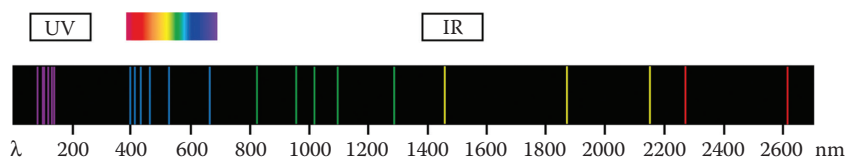


Figure L.139 Lyman series in optical decay of excited hydrogen states.

Lyophilization

[biomedical, energy] Mechanism of extraction of water (dehydration) relying on a rapid FREEZING process allowing for SUBLIMATION to remove the water without allowing for biological degradation. Primarily used to preserve biological media that are subject to loss of cellular integrity as well as chemical break down. The cold temperatures slow down the chemical processes (*also see* CRYODESICCATION).

Lysosome

[biomedical, chemical] Organelle in biological CELL that has a digestive function. These cellular pockets contain ACID hydrolase enzyme that is used to assimilate cellular waste material as well as foreign materials and debris produced in the regenerative cellular process (see [Figure L.140](#)).

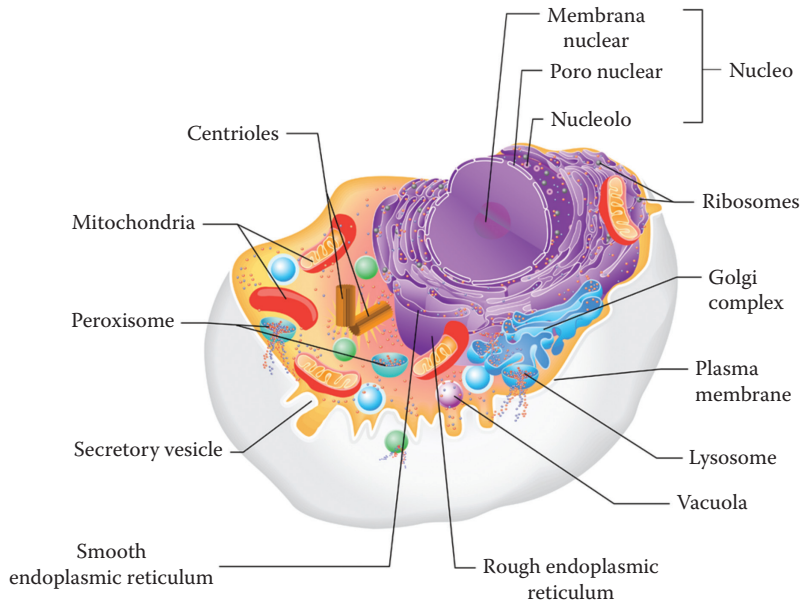


Figure L.140 Lysosome as essential constituent of cellular organism.



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MacCormack method

[computational, fluid dynamics, thermodynamics] A NUMERICAL method used in solving fluid-dynamic problems. The method resembles the finite ELEMENT method used in solving the EQUATION OF RADIATIVE TRANSFER in electromagnetic transport. The discretization process will allow solving complex integro-differential equation of orders equal or higher than 3. One specific example is in the calculations with respect to shock waves associated with a SUPERSONIC FLOW. The approach applies, for instance, to the KORTEWEG-DE VRIES EQUATION, which is to the third order in spatial coordinates and first order in the temporal dimension.

Mach, Ernst (1838–1916)

[acoustics, fluid dynamics, general] Austrian physicist whose work in shock waves (in 1877) led to name the supersonic phenomena to be classified under the MACH NUMBER. The “Mach waves” are produced by object traveling faster than the speed of SOUND. The general concepts of Ernst Mach’s philosophy involved specific concepts of INERTIA that freed ALBERT EINSTEIN (1879–1955) from the Newtonian physics ideologies and helped him design his Theory of Relativity principles. The work of Ernest Mach resulted in the development of the Mach number (Ma) (see [Figure M.1](#)).



Figure M.1 Ernst Mach (1838–1916).

Mach angle

[acoustics, fluid dynamics] Half angle of the cone describing the envelope of the pressure WAVE created under the Mach PROPULSION of an object or phenomenon traveling with a velocity v_{object} greater than the speed of SOUND (v_{sonic}): $\mu_{\text{Mach}} = \sin^{-1}(v_{\text{sonic}}/v_{\text{object}})$, the radius (r) of the cone expands with TIME (t) as

$r = v_{\text{sonic}} \times t$, whereas the cone is elongating with length $l = v_{\text{object}} \times t$. The angle outlining the MACH CONE itself is described by $\sin \theta = v_{\text{sonic}} / v_{\text{object}} = 1/Ma$ where v_{sonic} is the speed of sound, which has a sinus of the angle equivalent to the reciprocal Mach number (Ma). The concept was described by ERNST MACH (1838–1916) (see [Figure M.2](#)).

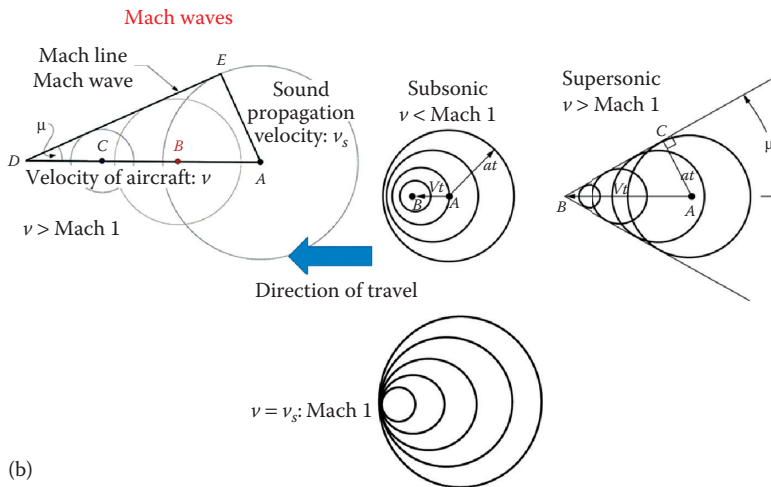
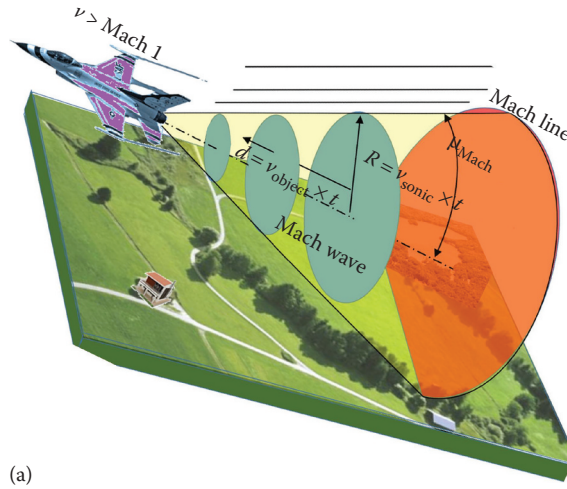


Figure M.2 (a) Mach wave and Mach-lines and (b) Mach angle for different condition.

Mach cone

[acoustics, fluid dynamics] Inside the Mach cone the SONIC BOOM is audible, whereas outside the Mach cone there is silence and no influence from the supersonic phenomenon such as temperature or pressure and FLOW can be observed (see [Figure M.3](#)).



Figure M.3 Mach cone.

Mach number

[fluid dynamics] ($Ma = v/v_{\text{sonic}} = \sqrt{Re \times Wi} = v\sqrt{\rho/E}$) Dimensionless number, developed by ERNEST MACH (1838–1916), indicating the ratio of the velocity (v) of a phenomenon, specifically fluid FLOW, to the speed of sound (v_{sonic}). The SONIC BOOM is an example of the velocity of an object crossing the speed of SOUND, releasing the compression of acoustic ENERGY (i.e., mechanical distortion, an object in MOTION will compress the FLUID directly in-front, superimposed is the propagation of the mechanical vibrations of the object itself) in a different form of acoustic energy. The Mach number defined by the material properties uses the DENSITY (ρ) and the Young's modulus (E), also called elastic modulus. In the definition the following are also used: the REYNOLDS NUMBER and the Weisenberg number. The seed of sound will be a function of the density of the fluid, and is hence slower at higher altitudes. A phenomenon at a velocity less than the speed of sound ($Ma < 1$) is considered subsonic, whereas a phenomenon at a velocity greater than the speed of sound ($Ma > 1$) is considered supersonic. The Mach number of the fluid flow over an AIRFOIL will initially increase and subsequently decrease before detaching at the end of the airfoil. Phenomena under Mach FLUID DYNAMICS have a temperature profile that follows a pattern dictated by the Mach flow conditions and are confined within the MACH CONE. While operating under compression above the Mach velocity, the phenomena are no longer ISENTROPIC. When a SUPERSONIC FLOW is suddenly interrupted, the temperature and pressure will change nonlinearly as described by $T_0 = T \left(1 + [(\gamma - 1)/2] M_\infty^2 \right)$, where T_0 is the stagnation temperature, T the static temperature (ambient), γ the compressibility, and $M_\infty < M_{\text{crit}}$ is lower than the critical Mach number M_{crit} , which indicates the initiation of supersonic flow at a velocity less than the Mach speed. Under the same conditions, the pressure correlates the stagnation pressure P_0 to the static pressure P (ambient) as $P_0 = P \left(1 + [(\gamma - 1)/2] M_\infty^2 \right)^{\gamma/(\gamma-1)}$, where for AIR the exponent is $\gamma/(\gamma - 1) = 3.5$. The Mach number is associated with various context applications of laws of similarity, defining the ratio of forces or parameters in dynamic phenomena by means of a dimensionless number. The laws of similarity correlate the boundary conditions and conditions such as length, time, and mass;

specifically expressed by INERTIA, transform to another similar case, ensuring that the equations remain invariant; acting as “scaling laws” (see Figure M.4).

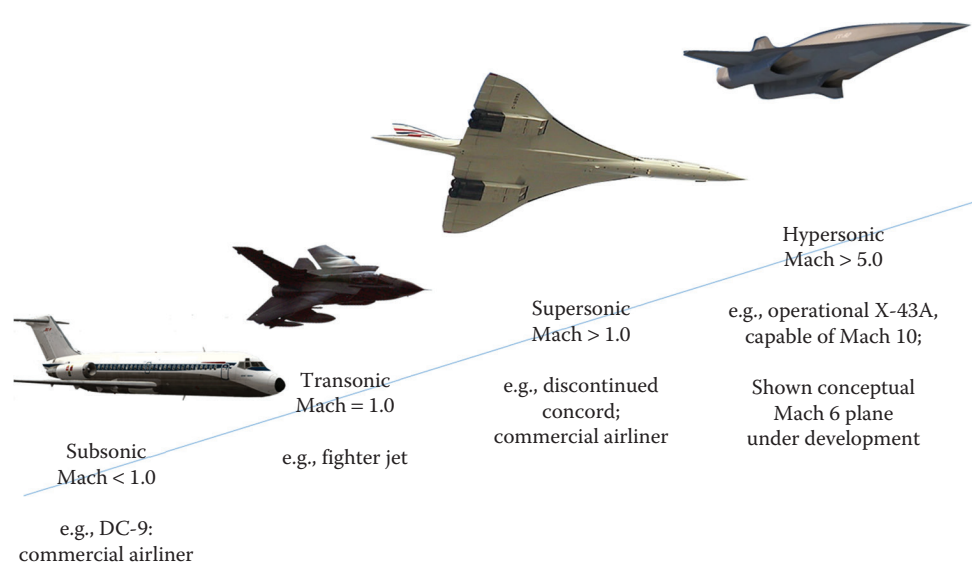


Figure M.4 Illustration of various objects traveling within certain Mach-number ranges.

Mach number, magnetic

[fluid dynamics] See MAGNETIC MACH NUMBER.

Mach number, sonic flow

[fluid dynamics] See SONIC FLOW.

Mach number, subsonic flow

[fluid dynamics] See SUBSONIC FLOW.

Mach number, supersonic flow

[fluid dynamics] See SUPERSONIC FLOW.

Mach wave

[fluid dynamics] Pressure WAVE generated by an object exceeding the speed of SOUND (Mach one; “sound BARRIER”), reaching supersonic velocity. The pressure wave results from the fact that the compression density EXPANSION or compression (i.e., FLOW) perturbation initiated by the moving object (sound wave) is overcome by the MOTION of the object, changing the direction of flow by an infinitesimally small ANGLE. The motion in the direction of the emitted sound wave is resulting in a compacting fluid due to VISCOSITY effects. Also referred to as “SONIC BOOM.” The Mach wave outlines the pressure OSCILLATION emitted by the moving object (e.g., fighter jet; expanding CAVITATION BUBBLE such as the one that is generated under ultrafast laser irradiation) connecting all crests that are in PHASE, forming a cone with the angle $\mu_{\text{Mach}} = \arcsin(1/Ma) = \arctan(v_n/v_{\text{sonic}})$, the MACH ANGLE, with Ma the MACH NUMBER. The Mach-wave flow direction in the angular expression (θ_{Mach}) is the differential of the Mach angle, and yields the PRESSURE (P) pattern $dP/d\theta_{\text{Mach}} = -(\gamma Ma^2/\sqrt{(Ma^2-1)})P$, with γ the compressibility of the FLUID in which the motion takes

place. The flow angle is derived from the Euler equation as $d\theta_{\text{Mach}} = (v_{\text{sonic}}/v^2)dv_n$, with $v_{\text{sonic}} = \text{constant}$ (the speed of sound), v the propagation velocity of the object introducing the perturbation, and v_n the velocity normal to the WAVEFRONT with respect to the WAVE propagation; assuming ISENTROPIC turbulent flow (see Figure M.5).

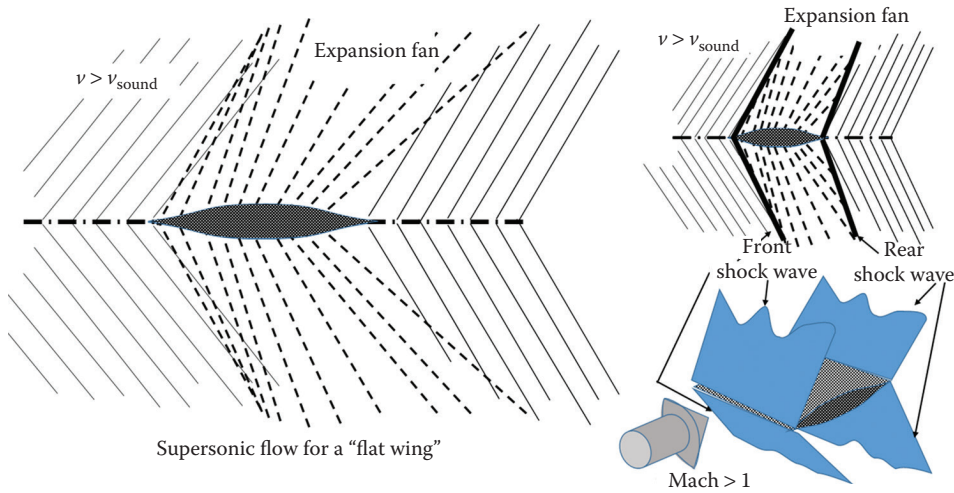


Figure M.5 Mach wave concept: side-view of the calculated flow distribution with respect to “characteristic” Mach waves in the supersonic velocity regime around an aerofoil with lenticular profile. The accumulation of lines representing equal flow-velocity provide an indication of location that will generate shockwaves.

Mach’s principle

[fluid dynamics, general] Hypothesis pertaining to the fact that all INERTIA in the UNIVERSE is the result of the interaction between all MATTER in the universe, proposed in 1872. This “invisible web” of interaction is also referred to as the “graviton particle,” the PARTICLE that ORBITS all mass to provide the gravitational COHESION between objects, stretching out to the interaction between galaxies. Named after ERNST MACH (1838–1916).

Mach–Zehnder interferometer method

[fluid dynamics, optics] Optical investigational mechanism devised by ERNST MACH (1838–1916) and LUDWIG ZEHNDER (1854–1949) based on INTERFERENCE, using a particular “by-pass” loop INTERFEROMETER design that is different from the established MICHELSON INTERFEROMETER of the time. Any interferometer uses a mechanism to split the path of a coherent source, such as a laser, to probe the material properties of a medium in one of the two paths. The difference in PHASE of the electromagnetic WAVE is a direct indication of the RELATIVE index of REFRACTION of the medium under investigation. The Mach–Zehnder interferometer uses transmission for the determination of the DIELECTRIC properties of the medium. In comparison, other interferometers such as the Fabry–Perot and Michelson interferometers use the backscattered or reflected light from a specimen (see Figure M.6).

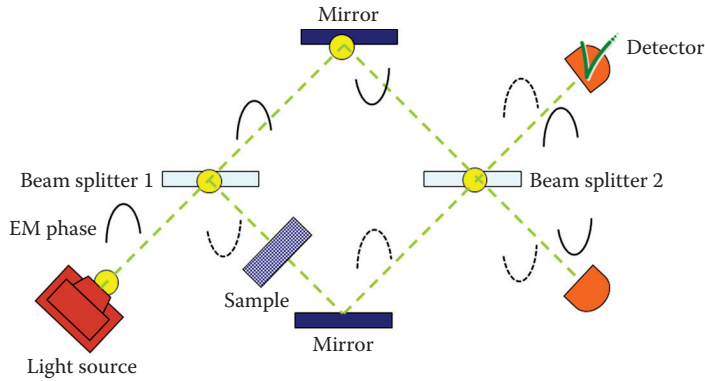


Figure M.6 Mach-Zehnder optical interferometer.

Machine, perpetual-motion

[general, mechanics, thermodynamics] See PERPETUAL MOTION.

Machines

[general, mechanics] Mechanical device designed to perform work. Machines are used to make repetitive and heavy activities less strenuous due to the introduction of an external ENERGY source that can perform a set number of ACTIVITY either under electronic or computer control or by means of mechanical gears or hydraulic FLOW. Geared machines use a toothed connection between axles to reduce the applied force to achieve the required force at the location of the desired action by means of torque, the force multiplied by arm length. The torque transfer between gears is directly proportional to the ratio of the teeth on the sprockets applied in the gear. In hydraulic and pneumatic machines, the force is reduced based on PRESSURE (P) applied to an area (A), where the final force ($F = PA$) is inflicted by an area that is larger than the area of fluid on the side where pressure build-up is introduced: $F_1/F_2 = A_1/A_2$, whereas the pressure is equal on both sides based on the COMMUNICATING VESSELS law (see Figure M.7).

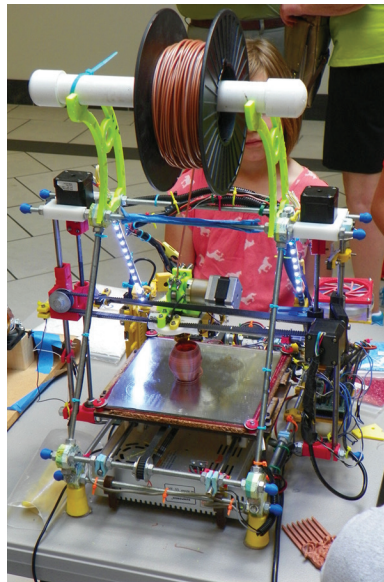


Figure M.7 Rapid prototyping machine constructed from bars and joints and fully functional, once attached to a microprocessor/computer system.

Maclaurin, Colin (1698–1746)

[astrophysics/astronomy, computational, fluid dynamics, mechanics] Mathematician from Scotland. In ALGEBRA, his contribution was a specific series derived from the Taylor series named the Maclaurin series. Additional geometric and calculus-based phenomenological work by Colin Maclaurin was with respect to the shape of rotating bodies presented in 1742 *A Treatise on Fluxions*. In this work, he described the ellipsoidal shape of the EARTH and how this would become more flattened in case the angular momentum increased. The contradictory realization in Maclaurin's work was the description that there will be an optimal configuration. Increasing radius as a result of increasing ANGULAR VELOCITY (ω) will in fact result in bringing the rotation to a halt based on the fact that the ANGULAR MOMENTUM (L) cannot strive for infinity; $L = \omega I$ when the MOMENT OF INERTIA I increases with increasing radius (r), where an infinite radius will define a flat Earth. The optimum will be attained when the earth's radius is approximately 20% greater than its current equatorial radius, with a matching angular velocity of $2.604 \times 10^{-4} \pi$ rad/s, 11 times our current rotation, decreasing the day to 2 h and 8 min (see [Figure M.8](#)).



Figure M.8 Colin Maclaurin (1698–1746).

Maclaurin ellipsoid

[astrophysics/astronomy, fluid dynamics, mechanics] Based on the *Treatise on Fluxions* published in 1742 by COLIN MACLAURIN (1698–1746), a deformation of a round object will run into an energetic dilemma with an increasing angular velocity. The deformation in a round object while spinning around its axis, where the ellipsoidal shape is assumed to increase its primary radius under a continuously advancing angular velocity, with an inherent increasing angular momentum. There is however an energetic constraint that will limit the increase in angular velocity once the optimal angular momentum has been exceeded, from where the ellipsoid

will decrease in angular velocity, while the radius would continue to increase. The expression for the shape of the ellipsoid is defined as $b = (\cos \theta / \sin^3 \theta) [\theta (1 + 2 \cos^2 \theta) - 3 \sin \theta \cos \theta]$, $b = \omega^2 / 2\pi G \rho$ (ρ density; G the gravitational constant; ω the ANGULAR VELOCITY for the rotating PLANET), $\cos \theta = c/a$, $0 < \theta < (\pi/2)$ (see Figure M.9).

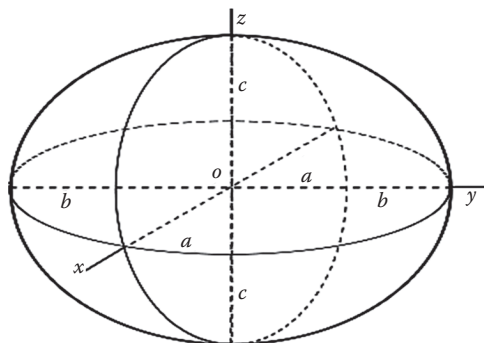


Figure M.9 Maclaurin ellipsoid.

Macromolecules

[biomedical, chemical] Molecules with a high molecular mass. Several POLYMER molecules will qualify as macromolecules, as many biological molecules, including the MOLECULE responsible for radiance VISION (gray scale, in RODS) Rhodopsin: molecular weight $35,200 \pm 1200$. Other examples are PLASTICS, graphene, carbohydrates, and DNA. The term macromolecule was introduced in the early 1920s by the German chemist Herman Staudinger (1881–1965) for molecules with in excess of 1000 atoms (see Figure M.10).

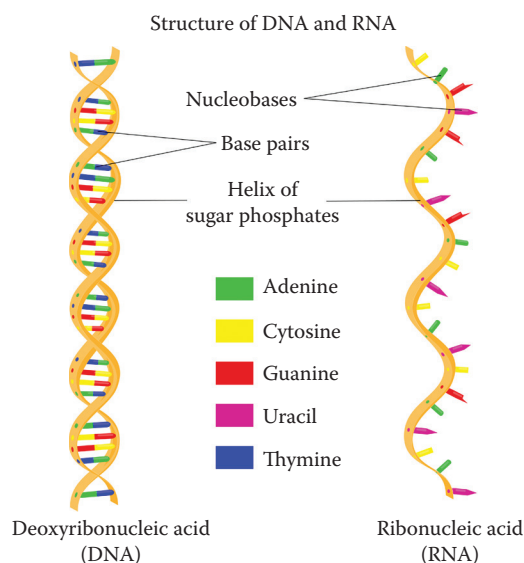


Figure M.10 Graphical representation of the biological DNA macro molecule (Deoxyribonucleic acid), encoding the genetic make-up of biological entities.

Macrophage

[biomedical] Cells that form the first line of attack in infections with the name derived from Greek meaning “large eater.” The macrophage performs an active mechanism of encapsulating bacteria or viruses and rendering each individually inactive. The macrophage is approximately three-times the size of a red BLOOD CELL (see [Figure M.11](#)). The macrophage is a biological single cell organism that performs active invagination (“consumption” through the CELL MEMBRANE). During this process the SURFACE TENSION is locally modified.

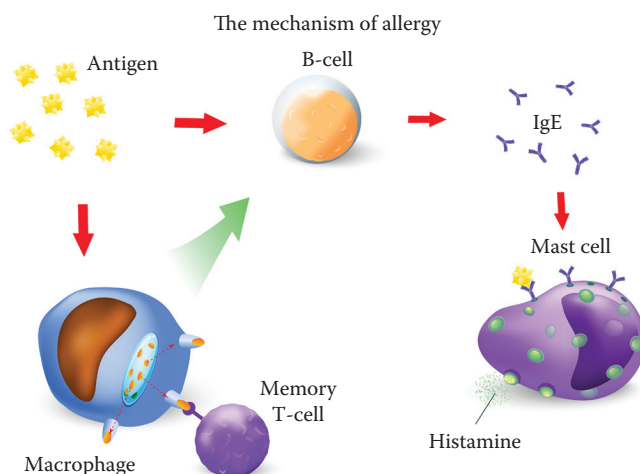


Figure M.11 Macrophage mechanism, in this case as it applies to an immune response.

Macroscopic

[biomedical, chemical, general, solid-state] Either directly visible by the naked EYE, requiring no additional visual aids to identify the characteristics; or larger in scale than atomic or molecular level, identifying the mechanical and/or fluid-dynamic features of a constituent.

Magic nucleus

[nuclear, solid-state] The NUCLEAR FORCE holding the NEUTRON and protons together appears to be saturable, leaving distinct numbers of nuclides to have a stable configuration due to the fact that each bond NUCLEON interacts only with a few of its nearest neighbors. Magic nuclei have a certain (magic) number of neutron (N) or protons (Z): 2, 8, 20, 28, 50, 82, and 126, which are more tightly bound than nuclei that do not possess nuclides in magic number format. The nuclear magic number performs a similar function as the atomic number for noble gases; pertaining to atomic PHYSICS. The magic number represents a closed (full) PROTON of the neutron shell (*also see* BINDING ENERGY *and* SHELL MODEL).

Magnet

[astrophysics/astronomy, biomedical, energy, quantum, solid-state] Device or object with two POLES that form MAGNETIC FIELD lines connecting from one “positive” pole to a “negative” pole. The magnetic mechanism of action is the result of molecular-sized eddy currents that generate a magnetic field as described by AMPÈRE’S LAW, either molecular-sized eddy currents or larger MACROSCOPIC currents in well-defined conductors. A magnet by definition can only have two balanced poles (i.e., both poles are equally strong to ensure that all magnetic field lines are closed), whereas electric field lines can be produced from a single charge concentration. There are three classes of magnets: (1) permanent magnets, (2) electromagnets (e.g., solenoids), and (3) temporary magnets. A special class of magnet is the QUANTUM MAGNET. Permanent magnets have a constant magnetic field over a finite life-time, which may be extensive in duration. The

EARTH has a magnetic field and is classified as a PERMANENT MAGNET, other permanent magnets are ferromagnetic metallic structures as well as ores. Permanent magnets can lose the magnetic attribute resulting from exposure to high temperatures (random vibrational MOTION will disrupt the alignment of the individual magnetic fields generated by the localized eddy currents), mechanical shock (mechanical vibrations, will miss-align the eddy currents in the medium) or exposure to another external magnetic field. Electromagnets derive the magnetic field from a current applied to a conductive circuit that forms the magnetic field only when the current is flowing. One powerful example of electromagnets is the SOLENOID. Electromagnets are for instance used in MEDICINE for MAGNETIC RESONANCE IMAGING (MRI) as well as in electron microscopes for beam-steering next to MAGNETIC LEVITATION for transportation purposes. In consumer applications, magnets are used for door-closer (both permanent magnets [passive] and electromagnets [active]) as well as in compass for directional orientation. Temporary magnets are forming magnetic capabilities based on the confluence of several phenomena that all need to be present at the same time, and will disappear voluntarily as well. A relatively new class of permanent magnets is the “rare-earth magnet,” identified by the relatively high magnetic field strength per unit mass. The rare-earth ELEMENTS can be magnetized because their four “f” electron orbitals (as described in the BOHR ATOMIC MODEL) are not filled. The orbitals are the subpart of the shell that in turn is the subpart of the shells. Shells are grouped and named as follows: K, L, M, N, O, P, and Q. The subshells are named as s, p, d, f, and g. In the Bohr atomic model, the f shell may contain a total of 7 pairs of electrons, 14 in total, each with spins pointing in one direction, in accordance with HUNDS’ RULE. Having these electrons aligned gives rise to stronger magnetic fields. Rare-earth magnets are made from rare-earth elements, which entails primarily costly resources, not directly occurring in small quantities, rather only obtainable or produced in small quantities (e.g., Nd-Fe-B and Sm-Co). Typically these are compounds or composites that have IRON (Fe) as part of the matrix.

Magnetic

[astrophysics/astronomy, energy, nuclear, solid-state] The phenomenon and condition of possessing MAGNETIC FIELD lines, more specifically, being a MAGNET. (*see* MAGNETIC FIELD) (*see* [Figure M.12](#)).



Figure M.12 Magnet used in scrap yard (i.e., electromagnet), hauling junk metal.

Magnetic axis

[electromagnetism, geophysics] The axis connecting the earth’s MAGNETIC NORTH POLE to the MAGNETIC SOUTH POLE. This is not the same axis that connects the GEOGRAPHIC NORTH pole to the GEOGRAPHIC SOUTH pole. The magnetic axis is not fixed, and has switched 180° several times over the past millions of years. Based on geological

findings, there is evidence suggesting that the NORTH and south poles may have totally switched positions more than 65 times over the past 600 million years. See PALEOMAGNETISM and POLES (see [Figure M.13](#)).

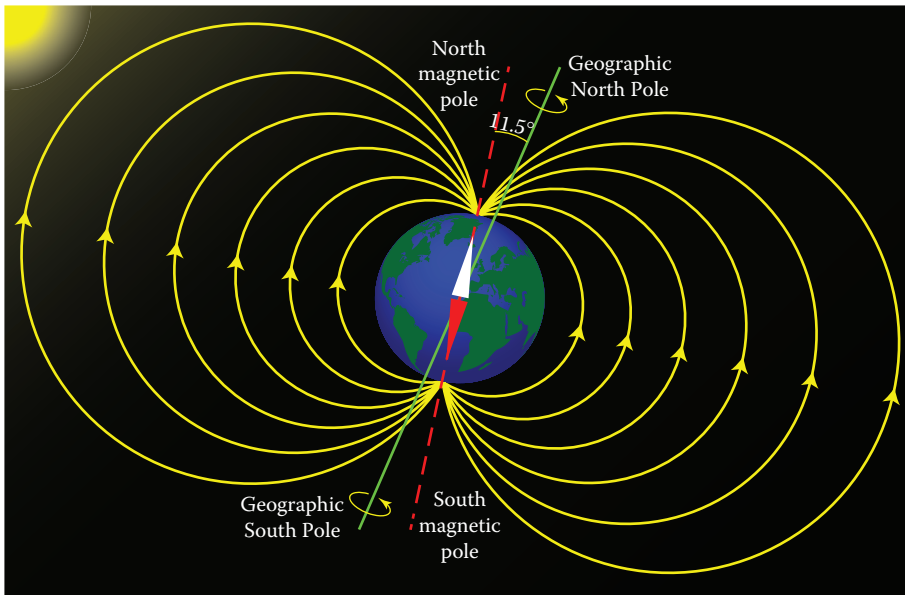


Figure M.13 Magnetic axis versus the geographic axis of the Earth.

Magnetic buoyancy

[astrophysics/astronomy, energy, geophysics] Due to a gradient in magnetic flux-tubes in the solar structure, the MAGNETIC FIELD at the solar surface will be smaller than on the interior, as will be the associated magnetic pressure. Based on the application of the GAS LAW, the density will be less inside the FLUX tube than in the main volume of the Sun. The internal magnetic field can make portions of compressible FLUID less dense than its surroundings, resulting in an upward FLOW under the influence of GRAVITY, the denser “heavier” medium surrounding the less dense medium is pushed out by gravitational buoyancy. This mass imbalance

creates a hydrostatic pressure with resulting flux tubes, providing the mechanism of action for eruptions resulting from magnetic buoyancy (e.g., solar flare) (see [Figure M.14](#)).

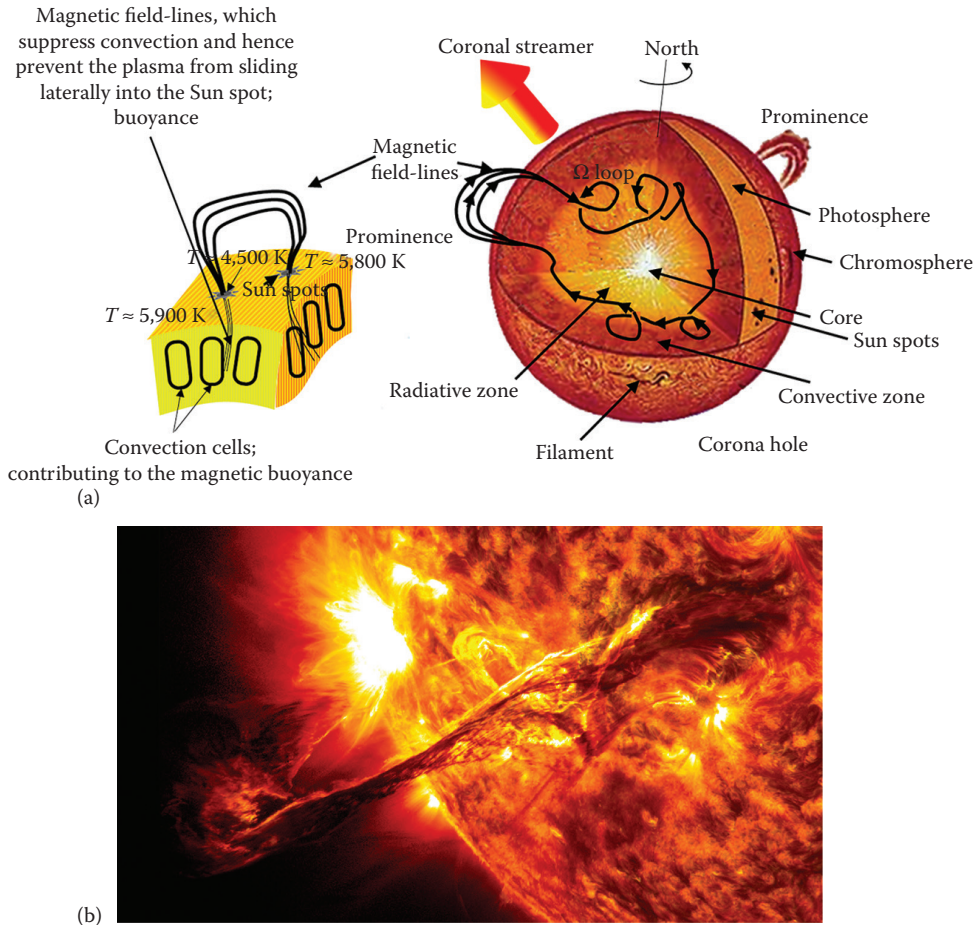


Figure M.14 (a) Magnetic buoyancy in the plasma layers within the sun's volume and (b) solar flare.

Magnetic cooling

[atomic, nuclear] At extremely low temperatures (especially below $T = 1\text{ K}$), it becomes difficult to decrease the temperature of a medium by ordinary means. The use of adiabatic magnetization has been successful for both paramagnetic salts and nuclear cooling, introduced by the chemist William Francis Giauque (1895–1982) from the United States in 1933 for salts, and by means of NUCLEAR MAGNETIC MOMENT in 1955 for cooling of the atomic core by the physicist Nicholas Kurti (1908–1998) from Hungary and by PETER DEBYE (1884–1966) from the Netherlands. The phenomenon was however observed prior to this in 1917 by the physicist Pierre-Ernest Weiss (1865–1940) from France, and the physicist A. Piccard (1884–1962) from Switzerland in 1917. For salts, the ENTROPY (S) can be controlled by an externally applied magnetic field (B) based on the TOTAL ANGULAR MOMENTUM (with quantum number J) as $S = R \ln(2J + 1)$, with $R = 8.3144621(75)\text{ J/Kmol}$ the universal gas constant. Similarly, for the NUCLEUS, the NUCLEAR ANGULAR MOMENTUM is I , with entropy $S = R \ln(2I + 1) - (1/2)\Lambda(B/T)$, where Λ is the Curie constant. For the nuclear cooling, the temperature reduction, starting at an initial temperature $T_i \propto mK$ (specifically $T_i < 20\text{ mK}$) under ADIABATIC DEMAGNETIZATION by means of ISENTROPIC reduction of the applied MAGNETIC FIELD from B_i to B_f , yields: $T_f = T_i/B_i \sqrt{(B_f^2 + b_m^2)}$, with b_m the internal magnetic field of the nucleus of the ELEMENT or alloy (e.g., for copper nuclei: $b_m = 0.3\text{ mT}$). Another form of magnetic cooling that applies to the

free electrons in a CONDUCTOR (with temperature T_e), with respect to the nuclear SPIN temperature T_n , yields: $T_e/T_n - 1 = \mu_0 \kappa_K [\dot{Q}_e / \Lambda(B^2 + b_m^2)]$, where κ_K is the Korringa constant and $\dot{Q}_e$ is the rate of heat exchange due to the freely moving electrons. Additional mechanisms of nuclear cooling by means of magnetic field involve the use of polarized magnetic field, and the change of direction of POLARIZATION with respect to the nuclear alignment, next to cooling in cascaded stages with different DOPING materials for a specific medium (see [Figure M.15](#)).

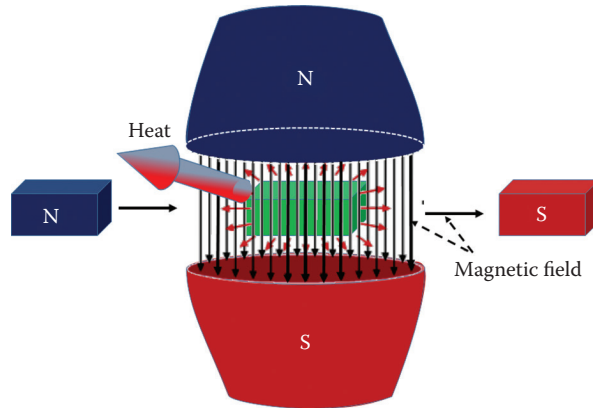


Figure M.15 Outline for the concept of magnetic cooling.

Magnetic dipole

[electromagnetism, general] Two POLES of equal and opposite MAGNITUDE at a fixed DISTANCE. A prime example is the BAR MAGNET. An ATOM can also form a magnetic dipole based on the angular momentum of the electrons, and more specifically when the atomic structure has unpaired electrons. The magnetic dipole is characterized by a magnetic dipole moment. The electrons in the atomic structure act as current loops, however without a fixed orientation (not providing a SOLENOID configuration). In electric circuits, a closed current loop, that generates a MAGNETIC FIELD perpendicular to the plane of the loop in a direction based on the right-hand rule. The current loop will generate a torque ($\vec{\tau}$) when exposed to an external magnetic field ($\vec{B}$) expressed as $\vec{\tau} = \vec{M}_{\text{current}} \times \vec{B}$, where $\vec{M}_{\text{current}}$ is the magnetic dipole moment of the current loop (see [Figure M.16](#)).

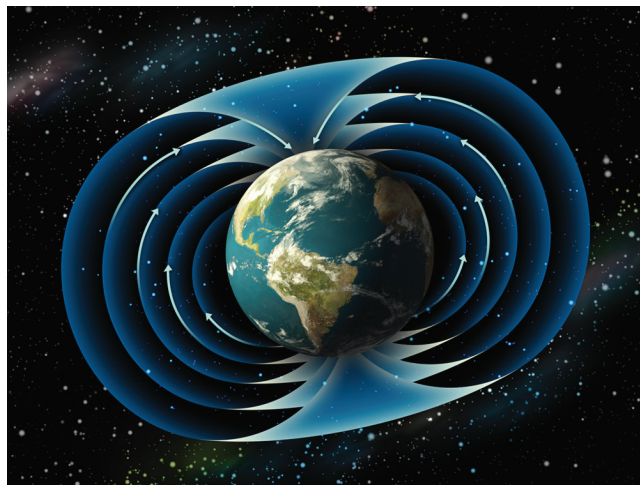


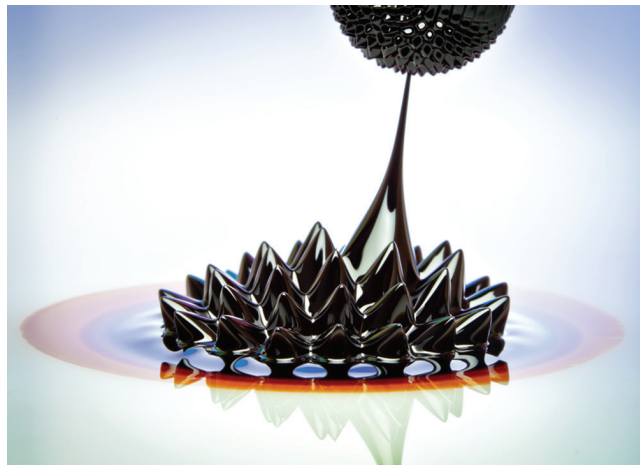
Figure M.16 Magnetic dipole: Earth with the central magnetic portrayed as a bar magnet; magnetic field lines encapsulating Earth in equimagnetic concentric toroidal shells. Note: the earth's magnetic north pole is on the geographic south side.

Magnetic dipole moment ($\vec{M}_{\text{current}}$)

[general] The potential of a current loop to express itself with a torque, defined as $\vec{M}_{\text{current}} = NIA\vec{n}$ where I is the current in the loop, N is the number of loops in the device carrying the current, A is the area outlined by the loop, and $\vec{n}$ is a unit vector in the direction perpendicular to the plane of the loop; the direction can be found by applying the right-hand rule.

Magnetic field

[biomedical, electromagnetism, geophysics] {use: imaging (MRI), guidance (compass), actuation}—An electric current generates a magnetic field according to AMPERE'S LAW: $\vec{B} = \mu_0(I/2\pi r)$, with μ_0 the magnetic permeability of the medium, and r the DISTANCE to the current. The magnetic field direction can be derived using the "right-hand rule," where the fist of the right hand illustrates the current in the direction of the thumb and the fingers the direction of the produced magnetic field. The direction of the magnetic field lines is by convention from the *north* to the *south* pole, and magnetic field lines are always closed, which means they will in certain cases pass through the device generating the magnetic field. For a coil, the magnetic field strength is generated by a loop current and is $\vec{B} = N\mu_0(I/2r)$, with N the number of coil revolutions. The magnetic field lines for a coil are shown in the figure. Similarly the EARTH has a magnetic field that is generated by the FLUID CORE, which is FERROELECTRIC. The geological North Pole of the Earth is actually the pool indicated by the north pole of a compass MAGNET, and is as such truly a MAGNETIC SOUTH POLE. The earth's magnetic field is influenced by the SOLAR WIND, which deforms the magnetic field lines as shown in the illustration. The magnetic field lines on a global (close to the surface) level are influenced by geological phenomena and follows patterns as shown by the magnetic field line diagram in the following illustration using data from 1922 as published in "Westphal, W.H., Physik, Ein Lehrbuch für Studierende; Julius Springer, Berlin 1928." The earth's magnetic field also attracts charged particles, specifically those released from the Sun during a solar flare. The charged particles attracted by the earth's magnetic field are accelerated as they approach the pools and accelerating charges produce ELECTROMAGNETIC RADIATION, which is visible by the "NORTHERN LIGHTS" or AURORA BOREALIS as well as the AURORA AUSTRALIS ("Southern Lights"). Magnetic field can also be used for magnetic imaging when modulated by a RADIO-FREQUENCY (RF) pattern as in MAGNETIC RESONANCE IMAGING: MRI and fMRI. Another application of magnetic field attraction is in MOTION CONTROL, such as a VOICE COIL in a loud SPEAKER. Animals also use magnetic fields to orient themselves and locate prey as outlined in ELECTRORECEPTION (see Figure M.17).



(a)

Figure M.17 (a) Close-up of ferromagnetic fluid flowing between two adjacent magnets under the influence of the magnetic field-lines, as portrayed by the fluidic spikes. (Continued)

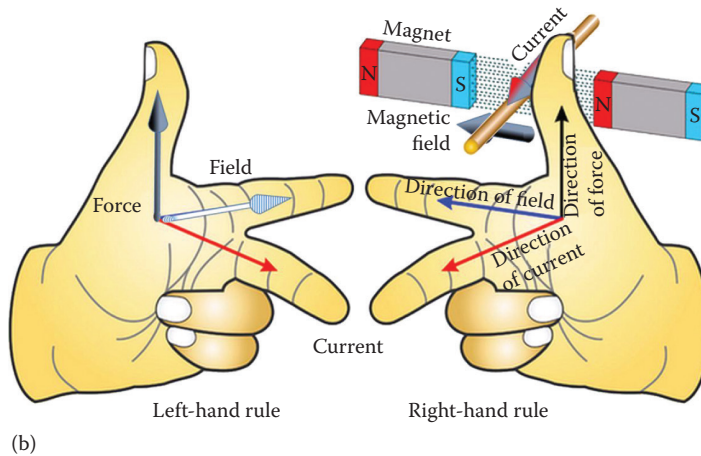


Figure M.17 (Continued) (b) Representation of the force relationship to the magnetic field using the right-hand rule, respectively, the left-hand rule.

Magnetic flowmeter

[biomedical, fluid dynamics] Flow of conductive media or charged particles will induce an electromotive force when exposed to an external MAGNETIC FIELD, hence allowing for noninvasive FLOW rate determination. The voltage generated is proportional to the MAGNITUDE of the magnetic field, the average flow rate, the density of the FLUID flow, as well as the length of the conducting medium flow tube. The measurement of the average flow velocity is based on the FARADAY LAW for electromagnetic induction. Magnetic flowmeters are used in fixed positions on conduits as well as in the format of a clamp-on for temporary flow verification. In medical applications, this type of flowmeter is used to measure the BLOOD flow locally in surgically exposed vessels for diagnostic purposes (see [Figure M.18](#)).

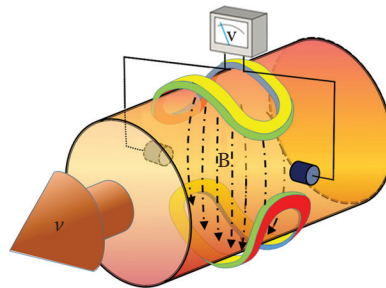


Figure M.18 Magnetic flowmeter principle, using the perceived flow of charges represented as a current.

Magnetic flux (Φ_M)

[general] The magnetic field-line density for a MAGNETIC FIELD ($\vec{B}$) taken perpendicular to an area $\vec{A}$ as $\Phi_M = \vec{B} \cdot \vec{A} = |\vec{B}| |\vec{A}| \cos \theta$. The units for magnetic flux are tesla per square meter, which is weber (in honor of a magnetic pioneer from Germany: WILHELM EDUARD WEBER [1804–1891]) $1 (T/m^2) = 1 Wb$.

Magnetic force (F_M)

[general] The force exerted on charged particles by a MAGNETIC FIELD ($\vec{B}$) treats the moving particles with charge q and velocity $\vec{v}$ as a current under ANGLE θ with the applied field: $F_M = q\vec{v} \times \vec{B}$. The direction of the force follows the “right-hand rule.” For a confined current ($\vec{I}$) in a wire with length ℓ , the force becomes:

$F_M = \ell \vec{I} \times \vec{B}$. This is the force that provides the mechanism-of-action for the formation of the AURORA BOREALIS, the charge stream emitted from the Sun under the earth's magnetic field (*also see* LORENTZ FORCE and AMPÈRE'S LAW).

Magnetic levitation

[electromagnetism, mechanics] Several versions are available, but the main principle remains the induction of a current in coils mounted in a wagon that produces an inherent MAGNETIC FIELD that is opposite to the inducing magnetic field applied from the outside, resulting in repulsion. The induction is based on the FARADAY LAW (described by the English physicist MICHAEL FARADAY [1791–1867] in 1831) and LENZ'S LAW (as introduced by the Russian/Baltic/German physicist HEINRICH FRIEDRICH EMIL LENZ [1804–1865]). The external magnetic field is generated by means of coils mounted in a track that supports the wagon, the LEVITATION coils. The coils in the wagon are ideally superconductors to minimize the resistive loss of current. The PROPULSION of the wagon is achieved by a second set of coils, in a separate location, such as the sides of the track. The propulsion coils are energized in a WAVE pattern along the length of the track, creating a temporal magnetic gradient, providing the magnetic force to move the wagon in the direction of the gradient. The wagon will “float” under the magnetic field repulsion, providing conditions of minimal FRICTION, apart from the AIR resistance during movement. As a fail-safe, there are wheels mounted underneath the wagon in cases when there is no external magnetic field (also found as maglev) (see Figure M.19).



Figure M.19 The concept of magnetic levitation applied to train transport.

Magnetic Mach number

[electromagnetism, fluid dynamics] In magneto-hydrodynamics, the forces are distributed based on origin, when the Lorentz forces are relatively equivalent to the inertial forces, this results in a relative equilibrium between the magnetic ENERGY and the kinetic energy. The LORENTZ FORCE (F_L) resulting from an external MAGNETIC FIELD ($\vec{B}$) $F_L = \vec{j} \times \vec{B}$, where $\vec{j} = \text{curl}(\vec{B}/\mu^*)$ is the associated current density, with μ^* the DIELECTRIC permeability. The inertial force (F_i) density is represented by the fluid DENSITY (ρ) and the velocity ($\vec{u}$) vector distribution described as $F_i = \rho \vec{u} \cdot \nabla \vec{u}$. The equilibrium in forces yields a Magnetic Mach number of approximately 1: $\mathcal{A}_{\text{Mach}}^2 = [((1/2)\rho u^2)/(B^2/2\mu^*)] \sim 1$. This is sometimes also referred to as the ALFVÉN NUMBER.

Magnetic materials, permeability of

[general] Material property that is representative of the MAGNETIC behavior of the medium. The magnetic permeability of VACUUM has been established as $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$, where the magnetic permeability of a medium can be referenced in relation to the permeability of vacuum by means of the RELATIVE PERMEABILITY ($0 \leq \mu_r \leq 1$) or as its own permeability $\mu_{\text{material}} = \mu_r \mu_0$. Ferromagnetic media generally have a relative permeability greater than 1, AIR and water can be described by $\mu_r \cong 1$ (deviation in the five decimal position or less), while for diamagnetic materials $\mu_r < 1$; $\mu_{\text{material}} < \mu_0$. For ferromagnetic materials, the magnetic permeability may not be constant, rather be a function of the applied MAGNETIC FIELD as well as a function of temperature.

Magnetic moment (μ_{mag})

[general, nuclear] The moment (compare with torque $[\tau]$ from mechanical force $[F]$ applied over an arm attached to a hinge point with length $[\ell]$: $\tau = Fd$) resulting from a magnetization ($\vec{m}_{\text{mag}}$) that is induced by a current loop ($\vec{J}$) in a volume of medium (dV) expressed as $d\mu_{\text{mag}} = \vec{m}_{\text{mag}} dV = (1/c) \vec{J} d\vec{S}$, where c is the speed of light and $d\vec{S}$ is the vector normal to the surface of the volume ELEMENT. The MAGNITUDE of the magnetic moment is $\mu_{\text{mag}} = (-e/c)(v/2\pi r)(\pi r^2)$, where e is the electron charge in Coulomb, $c = 2.99792458 \times 10^8 \text{ m/s}$ (the speed of light), and r is the radius of the orbit of an electron revolving with speed v . Alternatively $\mu_{\text{mag}} = -g_e \beta_m \vec{s}$, where $g_e = 2.0023...$ the Landé factor, the Bohr magneton $\beta_m = \hbar|e|/2m_e$ ($m_e = 9.10939 \times 10^{-31} \text{ kg}$ the electron mass), and the spin $\vec{s} = \hbar s$ (in this case specifically for an electron with the SPIN quantum number s and where $\hbar = h/2\pi$, which is PLANCK'S CONSTANT $h = 6.626 \times 10^{-34} \text{ J/Hz}$ divided by 2π). The electron will also have an orbital angular moment $\gamma_J = \mu_{\text{mag}}/\hbar J$, with J an integer. The current loop can be isolated in a small volume with neighboring volumes having a random orientation of the respective magnetization. While exposed to an external MAGNETIC FIELD or other influence, they may all line up to make the entire object a MAGNET (e.g., IRON). Object and media that are paramagnetic cannot be fully magnetized, only a fraction of the internal magnetic moments will line up under an applied field, increasing the total magnetic field strength, but marginally. Substances that are ferromagnetic can be magnetized (made to act as a magnet), and this is the result of the fact that the substance has a MAGNETIC SUSCEPTIBILITY. Although a diamagnetic medium has no internal MAGNETIC DIPOLE moment, it will have an effective magnetic field of its own in the opposite direction of an applied external magnetic field. Magnetic moments result from various currents such as orbital electrons, spin, and deuterons as well as ions to name a few.

Magnetic monopole

[general] The theoretical hold-out in the Gauss' law for MAGNETISM that relies on the fact that MAGNETIC FIELD lines have a starting point and an end point. In case the magnetic monopole would exist (so far no theoretical or experimental indication to the contrary is provided), the integral in Gauss' law will not render zero, right now it still holds for the integral over a surface (S) with surface area ELEMENTS da and normal vector $\vec{n}$ enclosing a magnetic field (B): $\oint_S \vec{B} \cdot \vec{n} da = 0$.

Magnetic north pole

[astrophysics/astronomy, general, geophysics] The pole on the earth's globe where the MAGNETIC FIELD lines originate, located near the GEOGRAPHIC SOUTH Pole. The magnetic field lines terminate at the magnetic south

pole, from where the magnetic field continues through the EARTH as a magnetic CONDUCTOR to re-emerge on the magnetic north pole, since per definition magnetic field lines form closed loops (see [Figure M.20](#)).

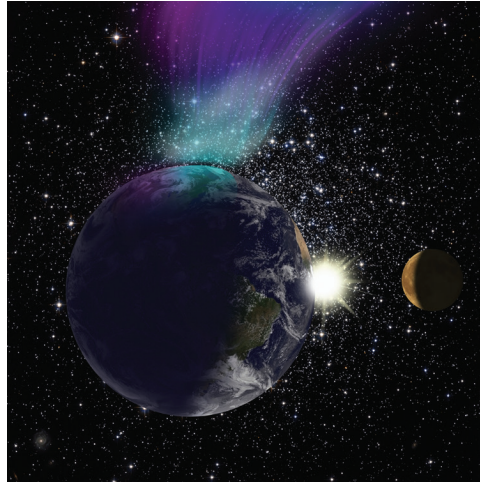


Figure M.20 Ions emitted from solar flares drawn in by the magnetic field pointing into the “North Pole” (Note: the geographic North Pole is the magnetic south pole). The resulting effect is expressed by the magnetic force accelerating the ions, hence generating the emission of electromagnetic radiation (i.e., the critical aspect of accelerated charge).

M

Magnetic poles

[general, geophysics] The locations on a MAGNETIC medium from where the MAGNETIC FIELD lines originate, respectively, are terminated, and continue through the material to form a closed loop. Solid state magnets are available in various shapes and sizes, most familiar shapes are the BAR MAGNET, horse-shoe magnet next to the solenoid ELECTROMAGNET. The EARTH acts as a bar magnet with a NORTH and south pole, providing a three-dimensional magnetic field loop. The magnetic field of the Earth is presumably the result of the rotational MOTION of the IRON inner core, acting as a current loop, as defined by AMPÈRE’S LAW, in close similarity to a SOLENOID. The POLES of the Earth’s magnetic field are not fixed and continue to “wander.” The earth’s magnetic field has changed orientation by 180° many times in the history of the Earth, the last time approximately 780,000 years ago. The magnetic field lines in the Earth’s ATMOSPHERE do not follow perfectly straight lines due to influences from magnetic media, such as granite, large bodies of water, and geographical topography (mountain ridges, valleys). A compass will align with the local magnetic field lines, hence providing a mechanism for identification of the locations of the magnetic poles. A compass indicating the magnetic poles can be used for orientation

purposes and planning a travel route, in comparison to the “global positioning system” that uses a chain of geo-synchronous orbit satellites to provide triangulation (see [Figure M.21](#)).



Figure M.21 Magnetic poles of bar magnets and horse-shoe magnet, “north” attracting “south.”

Magnetic quantum number

[nuclear] See QUANTUM NUMBER.

Magnetic resonance

[atomic, nuclear] Protons have a MAGNETIC moment, similar to a BAR MAGNET, that can be guided by an external MAGNETIC FIELD. A magnetic moment will precess around the externally applied continuous (steady-state) magnetic field with a frequency that is proportional to the magnetic field strength: the Larmor frequency. When applying an additional oscillating magnetic field that has an orientation perpendicular to the steady-state magnetic field, the magnetic moment can be “persuaded” to flip direction between SPIN states (“up” or “down”) when the OSCILLATION of the external field matches the LARMOR PRECESSION frequency. This principle specifically applies to a very simple magnetic moment: the proton. The proton’s magnetic orientation resonance ENERGY is emitted in the form of ELECTROMAGNETIC RADIATION in the RF spectrum. The RF spectrum can be detected externally, by applying a gradient in the magnetic field the Larmor frequency for the protons will be location specific, with associated differences in RESONANCE conditions. In this manner, the location specific magnetic resonance can be used for three-dimensional location specific SIGNAL collection. The use of several detectors will provide the line of intersect for each instantaneous RF signal, hence yielding the origin of the PROTON spin. The process of reconstruction based on the multiple lines of intersect and location specific magnetic field strength allows for three-dimensional imaging.

This magnetic resonance process is used apropos in magnetic resonance imaging (MRI), also referred to as nuclear magnetic resonance imaging (NMR imaging) (see [Figure M.22](#)).

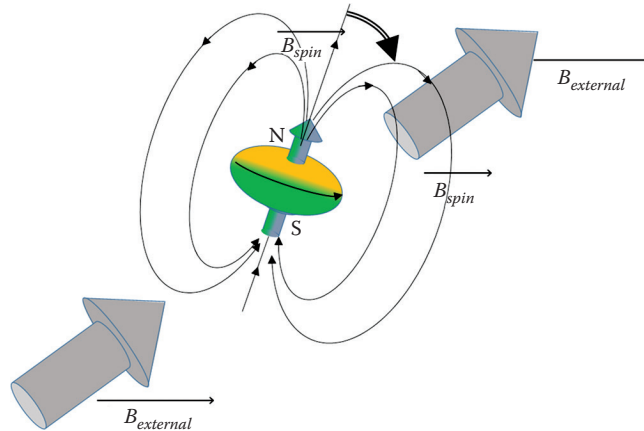


Figure M.22 A charged particle with nonzero spin will act as a magnet that will align with an external applied magnetic field, in particular it will continuously align with a changing external magnetic field and will be in sync with the frequency of the applied changing field, in resonance.

Magnetic resonance imaging (MRI)

[biomedical, electromagnetism, general, nuclear, quantum] Tomographic mechanism of action that generates images of imbedded physical and chemical properties by measuring the NUCLEAR MAGNETIC RESONANCE (NMR) signal emitted by individual and specific atomic and molecular structures with certain ENERGY configurations. The principle of NMR was first described in 1946 by FELIX BLOCH (1905–1983) and EDWARD MILLS PURCELL (1912–1997). It was not until 1973 that MR imaging was made feasible by Paul C. Lauterbur (1929–2007) and Sir Peter Mansfield (1933–), resulting in the implementation of the first clinical scanners by the beginning of the 1980s. The mechanism of action for MRI relies on nuclear excitation and subsequent electromagnetic emission of an inhomogeneous body of material, either biological or solid state by means of irradiation with electromagnetic waves in the range of RF. MRI is most known for its applications in MEDICINE for diagnostic screening. The photonic energy of the ELECTROMAGNETIC RADIATION is much less than what is used in ionizing radiation, such as X-RAY imaging and computed TOMOGRAPHY. The NMR phenomenon is fundamentally quantum PHYSICS. The phenomenon relies on the fact that all atomic nuclei possess an angular momentum with associated respective spins. Nuclei that have an odd number of protons, neutrons, or both have a discrete angular momentum. Hydrogen is one ELEMENT with those properties and is available in abundance in the biological entities such as the HUMAN BODY. The nuclear SPIN can be manipulated as if it were a tiny MAGNET due to the fact that a spinning charged PARTICLE creates an ELECTROMAGNETIC FIELD. When no external MAGNETIC FIELD is applied, the spins are oriented in a random fashion, hence canceling each other, with subsequent zero net magnetization. When an external magnetic field (B_0) is applied, the respective nuclear spins align themselves in the direction of the applied field as a function of time. Slightly more than half the spins align parallel to the direction of B_0 (the z -direction), while the remaining align in the opposite direction (down or antiparallel). The resulting net magnetization (M) points in the B_0 direction (longitudinal direction). The MR imaging concept relies on the fact that the local induced magnetic orientation will recoil to the base state once the external magnetic field is removed, or changes direction. Faraday's law mandates that a changing magnetic field induces an electric current that takes place in the detection mechanism in a receiver coil oriented perpendicular to the MAGNETIC field. The magnetization vector (M) is designed to oscillate and under external coercion will tip within the transverse xy plane. The spin axis will form PRECESSION around the z -axis with the Larmor frequency ω_{Larmor} , which is specific to the medium and the applied field as $\omega_{\text{Larmor}} = \gamma B$, where γ is the GYROMAGNETIC RATIO and B is the magnetic field strength. Thus, the transverse magnetization component M_{xy} induces a SIGNAL in the receiver coil.

RF excitation

The magnetization M is tipped into the transverse plane using an RF excitation pulse, which generates an external weak MAGNETIC FIELD (B_1) perpendicular to M , for example, in the x -direction. It should be noted that the B_1 field is not stationary; it is rotating in the xy plane around the z -axis with a Larmor frequency, ω_0 , in the same direction as SPIN precession, which creates the RESONANCE condition. During the period of time when B_1 is on, M lies under the influence of two magnetic fields: a strong stationary field (B_0) in the z -direction and a weak rotating field (B_1) in the xy plane orthogonal to B_0 . This results in M simultaneously precesses quickly around the z -direction with a Larmor frequency ω_0 , and slowly around the x -direction with a frequency ω_1 , where $\omega_0 = \gamma B_0$, and $\omega_1 = \gamma B_1$. This results in a spiral MOTION of M from the z -direction toward the xy plane. Because $\omega_1 \ll \omega_0$, M ends up tipped toward the xy plane with flip ANGLE depending on the RF pulse strength and duration. Excitation RF pulses are referred to with the angle by which the magnetization vector is tipped: for example a 45° RF pulse tips the magnetization vector half way into the transverse plane, while a 90° RF pulse tips the magnetization vector all the way into the transverse plane.

Bloch Equation

The Bloch equation describes the magnetization vector behavior under the NMR phenomenon: $dM/dt = M \times \gamma B$, where M = magnetization vector, B = magnetic field, t = time, and γ is the GYROMAGNETIC RATIO. The operator $\times$ (i.e., cross-product) in this case represents vector multiplication (see Figure M.23).

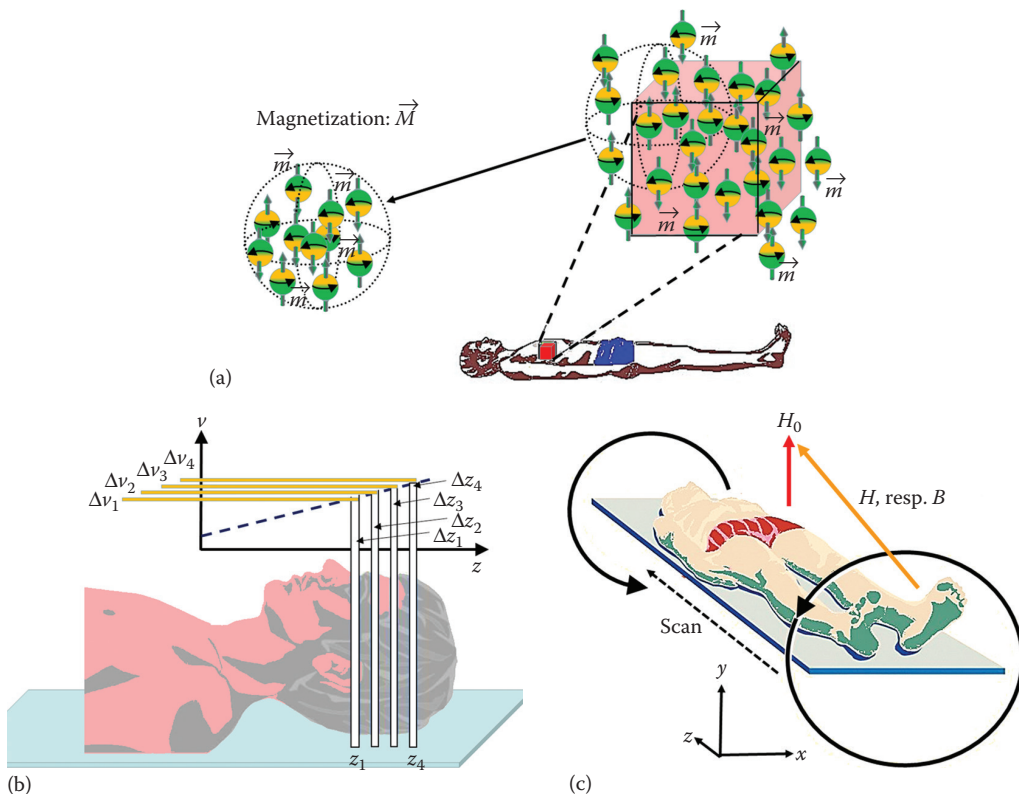


Figure M.23 (a–c) Concepts of magnetic resonance imaging. (Courtesy of Joint Base Langley-Eustis Newport-News, VA, USA.)

(Continued)



(d)



(e)

Figure M.23 (Continued) (d) MRI machine with patient and image reconstruction of magnetic resonance features associated with anatomical structures. (e) Open MRI unit. (Courtesy of Joint Base Langley-Eustis Newport-News, VA, USA.)

Magnetic Reynolds number

[computational, hydrodynamics, magnetism] See REYNOLDS NUMBER, MAGNETIC.

Magnetic South Pole

[general, geophysics] Physical terminal point for MAGNETIC FIELD lines on the EARTH as a MAGNET, located near the GEOGRAPHIC NORTH pole (northern hemisphere).

M

Magnetic spectrometer

[nuclear] Selective isolation of moving charged particles based on their kinetic ENERGY ($KE = (1/2)mv^2$, based on MASS (m) and velocity (v); using single value charges, the ELECTRIC FIELD (E) based acceleration will yield a uniform velocity potential) when exposed to an external magnetic field that causes the trajectory of the PARTICLE to curve due to the Lorentz force. The force on the CHARGE (q) results in an acceleration that provides a final velocity when the charge emerges from the ANODE of the accelerator potential with acceleration in the direction of the applied gradient in ELECTRIC POTENTIAL (V): $\vec{a} = q\vec{E}/m$. The loss in electric potential energy equates to the gain in kinetic energy as $q(V_2 - V_1) = (1/2)mv_2^2 - (1/2)mv_1^2$, providing the final velocity as a function of mass. The radius of curvature for the path of the moving charged particle exposed to a homogeneous, uniform, steady state MAGNETIC FIELD (B) is expressed by $r = mv/qB$. The terminal location of the particle on a linear sensor array is hence an indication of the mass of the particle. Using this principle, the chemical composition of an unknown material (constructed from a multitude of chemicals) can hence be deciphered, as well as the chemical structure and composition of

specific molecules, next to the analysis of SUBATOMIC PARTICLES in a CYCLOTRON. Also known as mass spectrometer (see BUBBLE CHAMBER and CLOUD CHAMBER) (see Figure M.24).

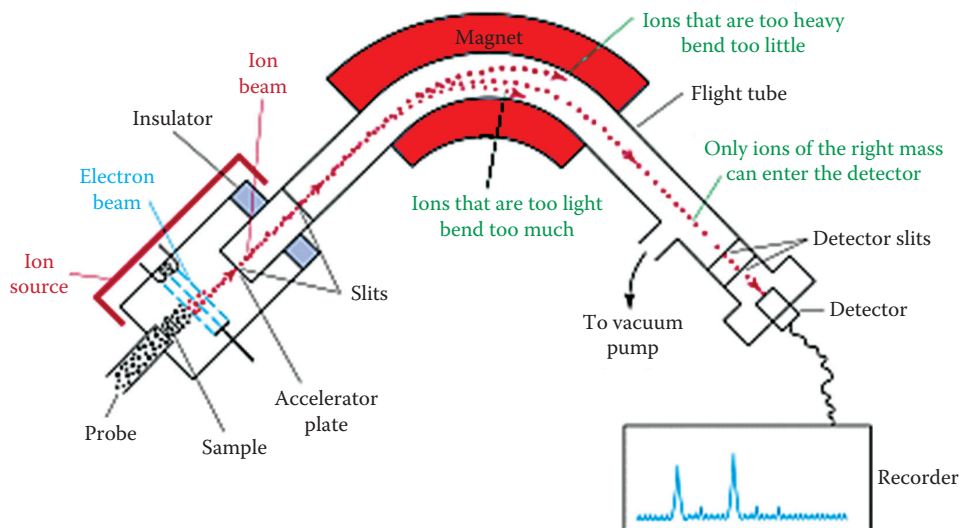


Figure M.24 Magnetic spectrometer, also known as mass spectrometer.

Magnetic susceptibility (χ_{mag})

[atomic, general, nuclear, solid-state] The tendency of individual MAGNETIC DIPOLE moments (μ_{mag}) within a substance to line up with an externally applied MAGNETIC FIELD as thermal agitation (at temperature T) will continue to mis-align the moments, expressed as $\chi_{\text{mag}} = \mu_0 N \mu_{\text{mag}}^2 / 3kT$, where $\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$ is the DIELECTRIC permeability of VACUUM, N is the number of magnetic dipoles per unit volume and $k = 1.380658 \times 10^{-23} \text{ J/K}$ is the Boltzmann constant. The principle was described by PAUL LANGEVIN (1872–1946).

Magnetism

[astrophysics/astronomy, energy, general, solid-state] The phenomena created by the MAGNET, more specifically by the MAGNETIC FIELD lines from a magnetic object (see MAGNET). The concept of magnetic field lines was illustrated in 1269 by Pierre de Maricourt (thirteenth century scientist; often quoted by his friend the English philosopher and friar ROGER BACON [1220–1292]), who shaped a LODESTONE into a sphere and placed IRON splinters on its surface and the METAL slivers aligned themselves with the magnetic field lines running from pole to pole, while at the pole they would stand erect, while the meridian circle would converge at the respective opposing POLES.

Magnetoencephalography (MEG)

[biomedical, imaging] Noninvasive imaging mechanism to study the ACTIVITY of the brain as a function of location in three-dimensional format. DEPOLARIZATION of single nerves creates a MAGNETIC FIELD in a similar fashion to an electric current in a wire (AMPERE'S LAW). The application of state-of-the-art magnetic sensors can detect the emerging magnetic field as a function of location in a tomographic imaging setting using the intersect of lines of detection for multiple sensor units. Magnetic sensors can detect a field strength as small as $1.0 \times 10^{-15} T$. Magnetoencephalographic imaging can provide high RESOLUTION details about the stimulated or spontaneous neural activities in the brain. Stimulated activation imaging provides significant details about potential damage to the brain as well as distinguishing from a mismatch in data communications to the brain (e.g., neurological damage to the main neurons leading to the brains such as the optic nerve and the auditory nerve). Generally the MEG imaging technique relies on arrays of SQUIDS (superconducting quantum INTERFERENCE devices) (see Figure M.25).

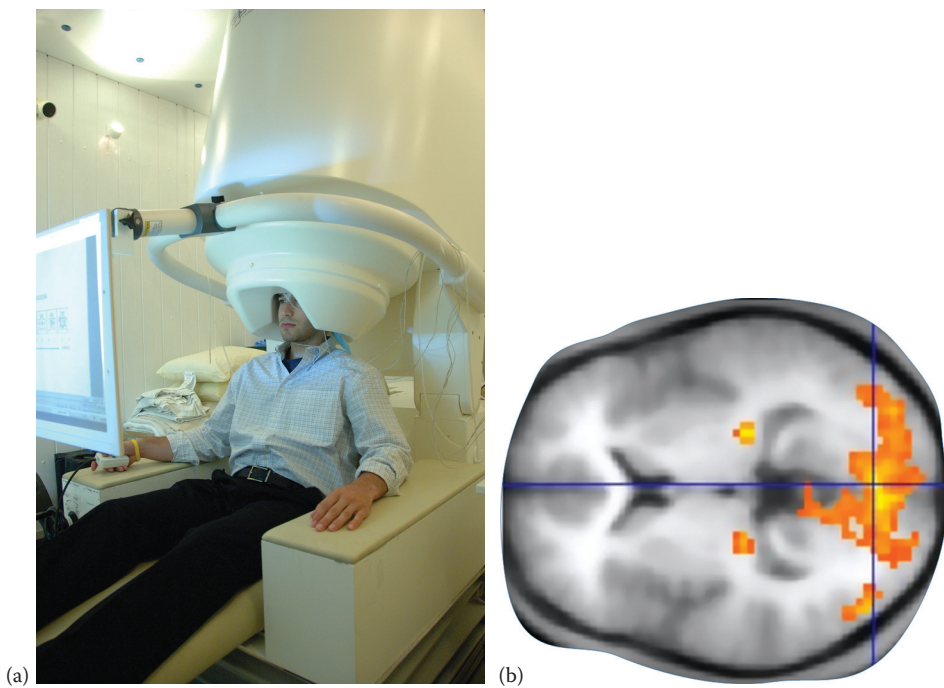


Figure M.25 (a) Magnetoencephalography machine used to image the brain activity. (b) MEG of a person performing mental tasks (frontal lobe activity).

Magnetohydrodynamics

[electromagnetism, general, mechanics] The FLOW of charged particles in any medium, ranging from PLASMA to ionic solutions. Seawater has a substantial electric conductivity due to its SALT content. The conductivity of seawater is $\sigma \cong 3.2 \text{ S/m}$. As a result of AMPÈRE'S LAW and Maxwell's revisions, the flow of electric particles in the earth's MAGNETIC FIELD generates a magnetic field of its own, expressed as $[\partial \vec{B}(r, t) / \partial t] = \nabla \times (\vec{u}(r, t) \times \vec{B}(r, t)) + \eta \nabla^2 \vec{B}(r, t)$, where $\vec{B}(r, t)$ is the FLUX density of the magnetic field, $\vec{u}(r, t)$ is the FLOW velocity of the FLUID, and $\eta \equiv (\mu_0 \sigma)^{-1}$ is the magnetic DIFFUSIVITY, with μ_0 the magnetic

permeability. One boundary condition follows from the fact that by definition there are no magnetic charges, and $\vec{B}(r, t)$ is solenoidal: $\nabla \cdot \vec{B}(r, t) = 0$. The Swedish electrical engineer and physicist HANNES OLOF GÖSTA ALFVÉN (1908–1995) has been attributed to be the founder of this particular field of PHYSICS (*also see* MAGNETIC MACH NUMBER).

Magneton

[atomic, nuclear] Expression for MAGNETIC DIPOLE moment resulting from a spinning spherical particle. This hypothetical spherical PARTICLE can be represented either by electrons in an orbit around the NUCLEUS next to the NUCLEAR MAGNETIC MOMENT as an independent phenomenon. The electron magnetic dipole moment, the BOHR MAGNETON, is expressed as $\mu_B = e\hbar/2m_e c$ where, $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the Planck's constant, m_e the electron mass, $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron charge, and c the speed of light. The nucleus considered as a “solid” sphere has a nuclear magnetic moment $\mu_N = e\hbar/2m_p c$, where m_p is the proton mass.

Magnetosphere

[energy, geophysics] The earth's MAGNETIC FIELD is inclined with respect to the EARTH'S ROTATIONAL AXIS at an ANGLE of approximately 11° . The magnetosphere interacts with the IONIC and ELECTROMAGNETIC events and in the IONOSPHERE this will create INTERFERENCE with communication in addition to the occurrence of the AURORA events (see [Figure M.26](#)).

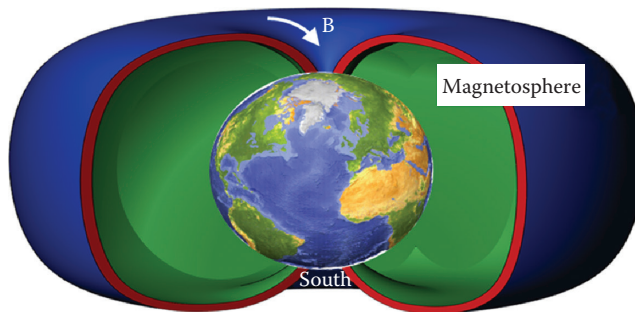


Figure M.26 Illustration of the earth's magnetosphere, and the influence of the sun's magnetic field.

Magnetostriktion

[imaging, solid-state] Change in the shape of an oscillating MAGNET under the influence of an external MAGNETIC FIELD. The magnet's shape change can be orchestrated by rearranging the molecular structure. Magnetic devices however appear to be limited to an upper modulation frequency of 500 kHz. This phenomenon can be applied for general SOUND generation as well as ULTRASOUND generation.

Magnetotactic bacterium

[biomedical, general] Bacteria that use **MAGNETISM** as a means to guide their path, the bacterial organism contains a chain of magnetite crystals, which create a functional compass needle. The magnetotactic bacteria were discovered in 1975 by Richard P. Blakemore (1950–) (see [Figure M.27](#)).

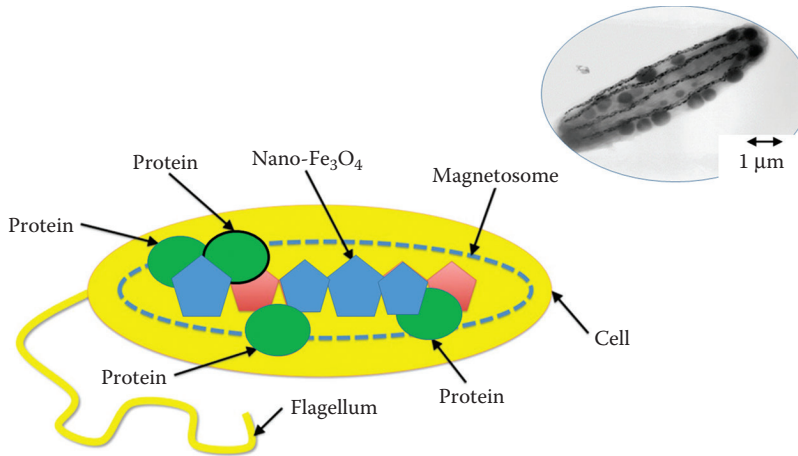


Figure M.27 Configuration of the mechanism-of action for Magnetotactic bacteria. Inset: Magnetotactic bacterium specimen.

M

Magnification (M_{mag})

[general, optics] The perceived increase (whole integer magnification) or decrease (fractional magnification) in size or details in an **IMAGE** formed with **ELECTROMAGNETIC RADIATION**, or electron beam. The **EYE** forms a real image on the **RETINA** that is smaller in size than the original object. A magnifying **GLASS**, microscope, or **X-RAY** machine forms an image that has a greater spatial resolution than can be observed with the naked eye. Generally, the **RESOLUTION** or **RESOLVING POWER** of an imaging system is a direct function of the probing **WAVELENGTH** (λ), limiting what can be distinguished is at minimum half the wavelength, or more formally the resolving power is defined by the **APERTURE** (D) of the device as $P = D/1.22\lambda$ (also see **RALEIGH CRITERION** and **ABBE CONSTANT**). The maximum resolution that is useful in a **MICROSCOPE** is on the order of $0.1 \mu\text{m} = 10^{-7} \text{m}$ at a magnification of $M_{\text{mag}} = 600$ times (although with artificial means $M_{\text{mag}} = 2000$ can be made efficient for diagnostic purposes), where the spatial separation of the **RODS** and **CONES** forms the limit factor in what can be discriminated to the lower level, next to the wavelength, usually taken on the average of the visible spectrum at $\lambda = 530 \text{nm}$. An **ELECTRON MICROSCOPE** uses an image forming mechanism based on the “**DE BROGLIE WAVELENGTH**” ($\lambda_{\text{deBroglie}} = h/p$) that involves electrons that can probe on molecular level and provide an extremely high spatial resolution better than $0.1 \text{nm} = 10^{-10} \text{m}$ with a magnification of the order of $M_{\text{mag}} = 10^6$; for instance at 10^5V acceleration potential, the de Broglie wavelength of the electrons is $\lambda_{\text{deBroglie}} = 4 \text{pm} = 4 \times 10^{-12} \text{m}$ (see [Figure M.28](#)).



Figure M.28 Example of Magnification, using a magnifying glass.

Magnification, angular

[general] See **ANGULAR MAGNIFICATION**.

Magnitude

[general] Length of vector, **NUMERICAL** value of parameter/tensor, signal strength, or reactivity of chemical reaction.

Magnus, Heinrich Gustav (1802–1870)

[computational, fluid dynamics] Scientist and chemist from Germany. Heinrich Magnus provides a significant insight into the phenomenon of **LIFT** with respect to objects in flight, specifically the deviation from a trajectory for bullets (see [Figure M.29](#)).



Figure M.29 Heinrich Gustav Magnus (1802–1870) in 1841.

Magnus effect

[fluid dynamics] Lift force explained by **HEINRICH GUSTAV MAGNUS** (1802–1870) in 1852. The **LIFT** applies to finned projectiles (wings may be a consideration, but the Magnus effect applies to vortices) as well as to other objects specifically when a form of rotation or **VORTEX** is involved (yawing or spinning projectiles),

such as a ball or bullet, and also applies to a rotating fan. The lift on a ball for instance is a function of the surface area (configuration, SURFACE ROUGHNESS, and size A), geometry (e.g., GOLF BALL), the inherent velocity (v), the orientation of the ball, as well as the rotation and the density of the FLUID medium (ρ). Magnus hypothesized that lift was derived from nonsymmetrical FLOW separation within the BOUNDARY LAYER of the PROJECTILE. The lift force, using a coefficient of lift (C_L), is defined as $F_L = (1/2)C_L\rho Av^2$. The Magnus effect is distinguishably noticeable for large objects, such as a volleyball being struck during a serve, making the ball float and suddenly visibly lift in an unpredictable trajectory (see Figure M.30).

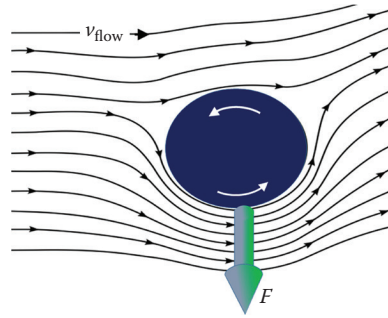


Figure M.30 Representation of the Magnus effect.

Magnus force

[computational, fluid dynamics] Force associated with vortices around a body in a FLOW (see MAGNUS LIFT).

Magnus lift

[fluid dynamics] “Lifting force” acting on rotating PROJECTILE bodies. A rotating body will provide an increase in pressure where the surface MOTION is in the opposite direction of the FLOW (according to Bernoulli’s law) causing disruption of the BOUNDARY LAYER, and lower pressure on the surface area that moves in the same direction as the flow, forming an eddy. The force vector on an object with a boundary layer vortex resulting from external flow conditions is $\vec{F}_{\text{Magnus}} = \kappa_i (\nu_{\text{vortex},i}, -u_{\text{irrotational},i})$, where $\nu_{\text{vortex},i}$ is the vortex flow velocity in the i th segment on the surface and $u_{\text{irrotational},i}$ the irrotational velocity resulting from neighboring vortices (derived from the VORTICITY $\omega_v(\vec{r}, t) = \nabla \times u(\vec{r}, t)$), and κ_i is the VORTEX “strength” of the i th vortex on the surface derived from the BIOT–SAVART LAW. Also known as KUTTA LIFT (see Figure M.31).

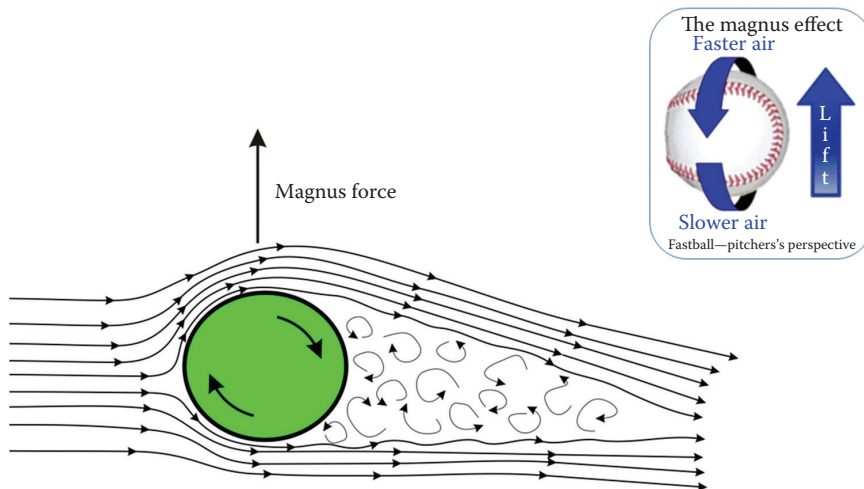


Figure M.31 Illustration of Magnus lift, with insert of the lift of a rotating base-ball, thrown by the pitcher.

Maiman, Theodore Harold (1927–2007)

[optics] American physicist, most known for constructing the first operational laser known, where laser is the acronym for light amplification by STIMULATED EMISSION of radiation. The laser made by Maiman was what is referred to as a ruby laser, made with chromium oxide crystal Cr_2O_3 . The invention of the laser is still under dispute between Maiman and GORDON GOULD (1920–2005) (see [Figure M.32](#)).

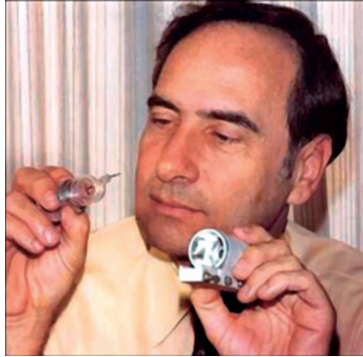


Figure M.32 Theodore Harold Maiman (1927–2007).

Malus, Étienne Louis (1775–1812)

[general] Physicist from France. In 1808, Étienne Malus, an engineer in Napoleon's army, discovered the POLARIZATION OF LIGHT waves. Malus was one of JEAN BAPTISTE JOSEPH FOURIER'S (1768–1830) pupils at the Ecole Polytechnique in Paris, France (see [Figure M.33](#)).



Figure M.33 Étienne Malus (1775–1812).

Malus's law

[general, optics] The radiance of unpolarized light (Ψ) transmitted through two polarizers on the same optical path with the relative ANGLE of the POLARIZATION direction between the two polarizers Θ expressed as $\Psi = \Psi_0 \cos \Theta$, where the minimum transmission is accomplished when the two polarizers are crossed, with the angle of polarization perpendicular. This was described by ÉTIENNE MALUS (1775–1812) in 1809.

Manhattan project

[atomic, nuclear] Code name for the development of the ATOMIC BOMB headed by Lieutenant General Leslie Richard Groves, Jr. (1896–1970), including the following scientists: NIELS BOHR (1885–1962), JAMES CHADWICK (1891–1974), Otto Frisch (1904–1979), ENRICO FERMI (1901–1954), and RICHARD PHILLIPS FEYNMAN (1918–1988) under the direction of ROBERT OPPENHEIMER (1904–1967) (see [Figure M.34](#)).



Figure M.34 Leader of the Manhattan Project: Lieutenant General Leslie Richard Groves, Jr. (1896–1970). (Courtesy of the US Department of Energy.)

Manning, Robert (1816–1897)

[fluid dynamics] Scientist and engineer from Ireland. Manning is known for his contributions to FLOW descriptions in rivers and canals (see [Figure M.35](#)).

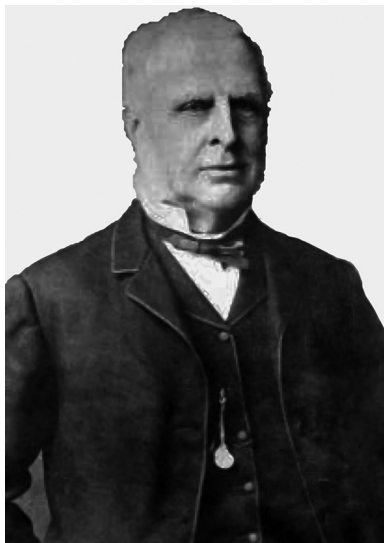


Figure M.35 Robert Manning (1816–1897).

Manning equation, open channel

[fluid dynamics] Open channel flow description introduced by ROBERT MANNING (1816–1897) in 1889 as an alternative to the Chezy equation. The Manning equation defines the FLOW (Q) as a function of flow area (A), the slope of the bottom of the channel (S_{slope}), as well as the ROUGHNESS of the walls and bottom (defined by the Manning roughness coefficient M_R listed in tables for various configurations), and the flow velocity as v : $Q = (1/M_R)AR_H^{2/3}\sqrt{S_{\text{slope}}}$, with R_H the hydraulic radius (the ratio of the cross-sectional area of flow to the perimeter of the wetted area, that is, the combined length of all the borders that are touching the LIQUID) (see Figure M.36).

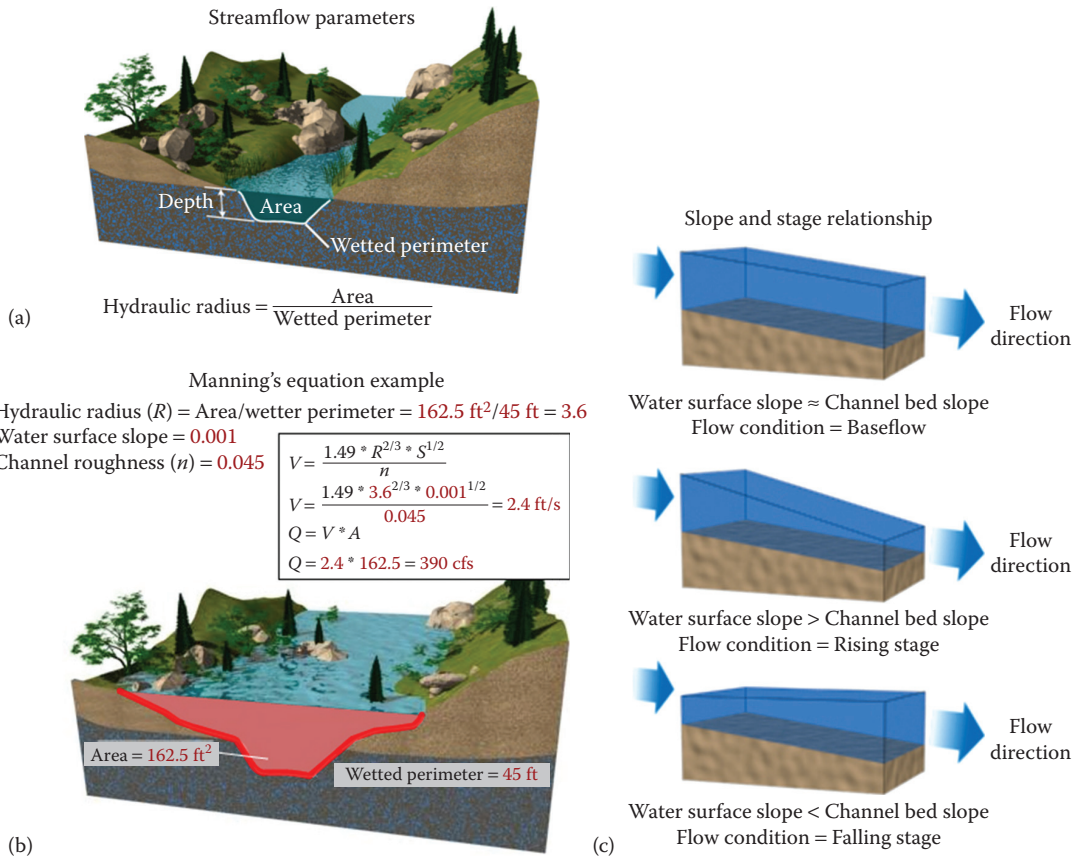


Figure M.36 (a–c) Examples of the implications of the Manning equation, based on simulations produced by The COMET® Program. (Courtesy of the University Corporation for Atmospheric Research (UCAR), and National Oceanic and Atmospheric Administration (NOAA), https://www.meted.ucar.edu/about_legal.php.)

Manometer

[fluid dynamics, general] Device designed to measure volumetric PRESSURE (P).

Pressure gauge

Used as a dial meter or as a liquid column. The height of a column (h) of LIQUID provides generally the mechanism of action to establish the pressure based on COMMUNICATING VESSELS transferring the force applied by pressure on a surface area (A) into a gravitational force (GRAVITATIONAL ACCELERATION g) of a cylinder of a liquid with mass $m = \rho V = \rho Ab$, with density ρ , eliminating the surface area to accommodate for pressure using $F = PA = mgb$, or $P = \rho gb$. A special manometer is used for the determination of BLOOD PRESSURE. An arm band is inflated by pumping AIR into a cuff and the cuff pressure is measured with a mercury (Hg) column in mm Hg. Blood pressure is used to check for arteriosclerosis and deviations in the

pump function of the HEART itself. The pressure in the blood vessels (artery in the elbow of the arm) is measured by listening for blood seeping through the constricted vessel as it opens up when the pressure in the cuff is slowly released. The sounds in the periodic FLOW pattern are referred to as KOROTKOFF SOUNDS. The arm pressure is roughly equal to the pressure at the heart since it is at level altitude, any deviation in height needs to be corrected for by the Bernoulli equation (see [Figure M.37](#)).

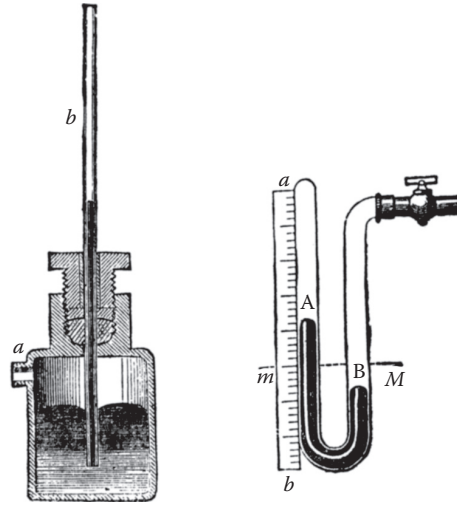


Figure M.37 Liquid-column Manometer.

Marangoni, Carlo Giuseppe Matteo (1840–1925)

[fluid dynamics, general] Scientist from Italy. Marangoni provided research on the effects on SURFACE TENSION due to spatial variations in a BUBBLE shape (e.g., pear, donut, and sphere) in 1865. The tangential (shear) forces at the surface due to influences from wind on a falling droplet or material inhomogeneities (e.g., dissolved chemicals) as well as temperature effects are referred to as Marangoni forces. One expression of a Marangoni surface tension force for a bubble (e.g., soap bubble) is the tangential force (T_s) as a function of the bubble WALL thickness (SKIN thickness τ_d) and local bubble layer density (ρ_s) as a function of the polar ANGLE (θ) with the reference frame at the “center” of the bubble with average radius R_0 (which may not be spherical), as a function of location in the reference frame ($\vec{r}$) expressed as $dT_s/d\theta = -(1/2)\rho_s(\vec{r})R_0\tau_d(r)g\sin\theta$, where g is the GRAVITATIONAL ACCELERATION. Note that the skin of the bubble has two surfaces where forces are acting (see [Figure M.38](#)).



Figure M.38 Carlo Giuseppe Matteo Marangoni (1840–1925).

Marcacci, Arturo (late 1800–early 1900)

[biomedical, optics] Scientist from Italy. Arturo Marcacci used his discovery of the toxicity of cinchonamine and quinine (generally alkaloids) in animal and plant cells when exposed to light to perform the first recorded photochemical procedure in BIOMEDICAL OPTICS in 1888.

Marconi, Guglielmo (1874–1937)

[electronics] Italian physicist. Marconi is best known for the development of the first operational RADIO transmitter in 1895. Based on his work in Great Britain, Marconi provided radio transmission between England and France in 1899, and had a company called the Wireless Telegraph and Signal Company, now named the Marconi Company, Ltd. (see [Figure M.39](#)).



Figure M.39 Guglielmo Marconi (1874–1937).

Maricourt, Pierre de (1220–1290)

[general] A.k.a. Petri Pergrinus, scientist from France who used needles made of MAGNETIC material to map out the patterns of MAGNETIC FIELD lines of naturally occurring magnetic materials. However, naturally occurring MAGNETISM (i.e., PERMANENT MAGNET) was supposedly already known in or before the tenth century before Christ (1000 BC) in our calendar. The MAGNET was named after the city in Greece called Magnesia where iron oxide was mined and its magnetic properties discovered. The official development of the compass is attributed to WILLIAM GILBERT (1540–1603) (see [Figure M.40](#)).



Figure M.40 Statue of Pierre de Maricourt (1220–1290).

Marine geophysics

[general, geophysics] *See* **HYDROLOGY**.

Mariner

[astrophysics/astronomy, general] Several spaceships launched from 1962 to 1972 by the United States; Mariner-2: 1962, trip to VENUS; Mariner-2: 1964, trip to Mars; Mariner-5: 1967 close range fly-by of Venus; Mariner-6 and 7: 1969, trip to the MARS polar regions; Mariner-9: 1971, orbit around Mars; Mariner-10: 1973–1975, trip to Mercury. The Mariner spacecraft series was followed by the Viking series in the 1970s (see [Figure M.41](#)).



Figure M.41 Spaceship mariner, Mariner-9 launched in 1971. (Courtesy of the National Aeronautics and Space Administration [NASA].)

Mariner

[geophysics] Nautical entrepreneur, sailor. Person associated with marine life in respect of traversing the globe on the water.

Mariner's astrolabe

[computational, general, geophysics] Instrument used by sailors in the seventeenth century for navigation at sea. The Mariner's astrolabe measures the altitude of the Sun as a function of the time of day to derive the

location of the vessel. The Mariner's astrolabe was developed by the Portuguese. The Mariner's astrolabe was replaced by the SEXTANT in the late seventeenth century (see [Figure M.42](#)).



Figure M.42 Mariner's astrolabe.

Markov, Andrey Andreyevich (1856–1922)

[computational] Mathematician from Russia (see [Figure M.43](#)).



Figure M.43 Andrey Andreyevich Markov (1856–1922).

Markov chain

[computational, thermodynamics] Mathematical process that is subject to changes due to changes in boundary conditions or changes in state, primarily based on statistical PROBABILITY and sequence (next state is the direct result of the previous state). The mathematical system is named after the Russian mathematician ANDREY ANDREYEVICH MARKOV (1856–1922). The Markov chain applies in particular to Monte Carlo methods and simulations in computational PHYSICS.

Markov chain mixing time

[computational, thermodynamics] The rate of convergence to a stationary process with respect to a finite MARKOV CHAIN. The mixing time is typically defined as the initial time frame (τ) over which the process distribution falls below a threshold that is small enough to result in a negligible error in the calculation (acceptable to the process), such as $1/e^2$ measured in “DISTANCE” or the MAGNITUDE between the sequential distributions Θ^1 (and more generally, Θ^p for a mixed system) at time τ and the stationary distribution.

Markov process

[computational, thermodynamics] See MARKOV CHAIN.

Mars

[astrophysics/astronomy, general, geophysics] Fourth planet from the Sun in the Earth’s SOLAR SYSTEM at a DISTANCE of 2.491×10^{11} m at its greatest distance (oval orbit, *also see* KEPLER). Mars has an equatorial diameter of 6794×10^3 m. The axial rotation of Mars is on average 24 h 37 min and 22.6 s, the revolution around the Sun is 686.980 earthdays. The PLANET Mars is also known as the “Red Planet” due to its colored appearance resulting from blowing red-dust clouds. Mars was visited by the US NASA program spacecraft, the Pathfinder, in 1997, next to a passing visit of the Mariners series and the Viking series of spacecrafts (see [Figure M.44](#)).

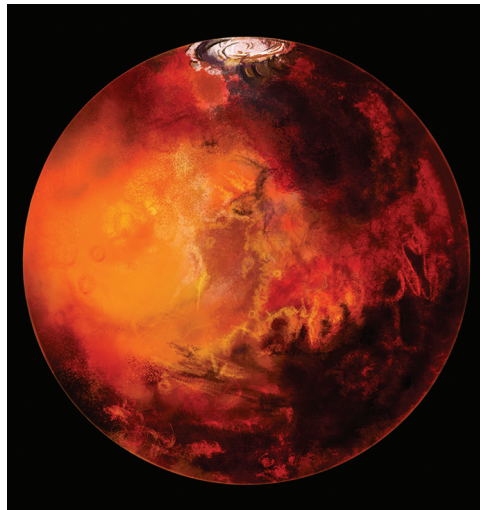


Figure M.44 The planet Mars.

Marsden, Ernest (1889–1970)

[atomic, nuclear] Scientist from the United Kingdom. Coworker of JOHANNES GEIGER (1882–1945) and contemporary and colleague of ERNEST RUTHERFORD (1871–1937) who worked on experimental determination of the ENERGY content of ALPHA PARTICLES around 1910. The experiment used thin METAL foils bombarded by alpha particles to observe the SCATTERING pattern, and most alpha particles went straight through, indicating their size

to be smaller than the LATTICE structure of the atoms in the foil. The backscattered alpha particles had to encounter same charge particles with a greater mass, later discovered as the NUCLEUS. (*Note:* the charge of the alpha particle was at the time known to be twice that of the electron and positive.) Based on the experimental observations of Marsden and Geiger, Rutherford proposed his model for the atomic nucleus in 1911 (see [Figure M.45](#)).

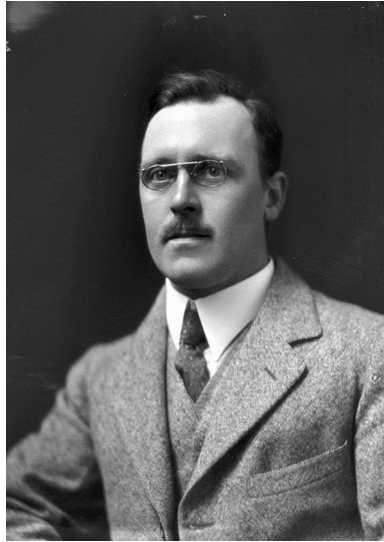


Figure M.45 Ernest Marsden (1889–1970) in 1921.

Marshak, Robert Eugene (1916–1992)

[atomic, computational, nuclear] Physicist from the United States. Marshak developed a theoretical description of the development and evolution of shock waves under the conditions of extremely high temperatures. One specific application of this field of research is in a nuclear explosion. The shock waves generated as the result of an ATOMIC BOMB are called “Marshak waves.” This explanation was the subject of a renewed interest a few years ago because it helped describe the consequences of a SUPERNOVA explosion. During his time at Los Alamos, Marshak worked with a select renowned group of physicists such as HANS ALBRECHT BETHE (1906–2005), NIELS BOHR (1885–1962), ENRICO FERMI (1901–1954), RICHARD PHILLIPS FEYNMAN (1918–1988), and ROBERT OPPENHEIMER (1904–1967) (see [Figure M.46](#)).



Figure M.46 Robert Eugene Marshak (1916–1992). (Courtesy of the Los Alamos National Laboratory.)

Marshak wave

[atomic, computational, nuclear] Shock WAVE generated during a nuclear explosion, also referred to as a THERMAL WAVE, or radiation DIFFUSION wave. The theoretical formulation was developed by ROBERT MARSHAK (1916–1992). Nuclear explosions are associated with RADIATION conduction, which is facilitated by photons traveling at the speed of light. The physical bounding velocity of thermal waves is much higher than ordinary explosions facilitating classical kinetic heat conduction, which is restricted by the speed of SOUND. The temperature profile of a thermal wave is markedly different from the GAUSSIAN DISTRIBUTION of linear heat conduction. In a nuclear thermal wave, the temperature in the heated zone is fundamentally constant everywhere radiating out from the source of the explosion, whereas near the front it rapidly drops to zero (see Figure M.47).

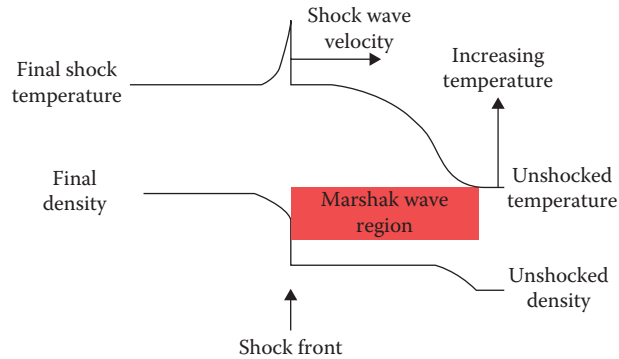


Figure M.47 Temperature profile for a Marshak wave.

M

MASER

[atomic, electromagnetism] Device that produces amplified MICROWAVE radiation by means of STIMULATED EMISSION (i.e., RESONANCE) phenomena in the host medium, developed approximately in 1954 by CHARLES HARD TOWNES (1915–2015) and ARTHUR SCHAWLOW (1921–1999) with their team at Columbia University in New York, NY and at the Lebedev Institute in Moscow by Nicolay G. Basov (1922–2001) and Aleksandr M. Prokhorov (1916–2002). All four received the Nobel prize for their efforts. Acronym for Microwave Amplification by Stimulation Emission of Radiation. The concept is based on the principle of stimulated emission introduced by ALBERT EINSTEIN (1879–1955) in 1917. Later this concept was found to work at shorter wavelengths using appropriate media, creating the LASER (see Figure M.48).

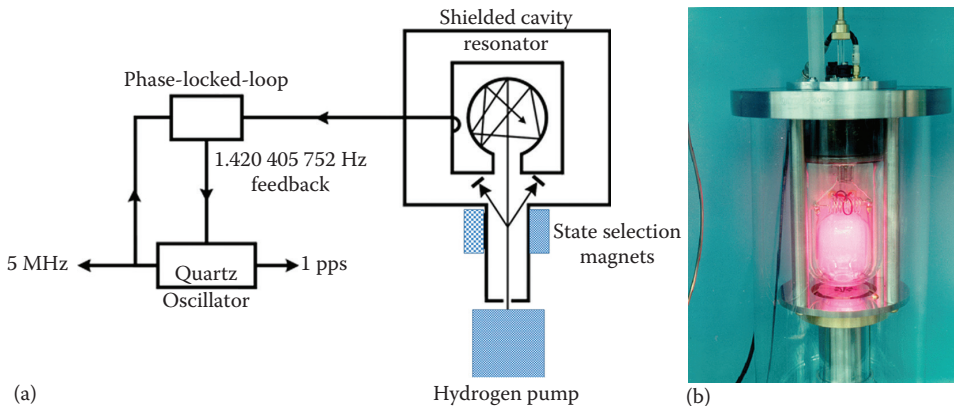


Figure M.48 (a) outline of the MASER oscillation principles, (b) Sealed glass tube used to confine a discharge in hydrogen at radio frequency, representing one of the fundamental elements inside a hydrogen maser. (Courtesy of Smithsonian Astrophysical Observatory; Jet Propulsion Laboratory (JPL)—Frequency Standards Laboratory/ National Aeronautics and Space Administration [NASA].)

Mass (m)

[general, nuclear] Measure of the INERTIA of a volume of substance of media, the physical presence irrespective of GRAVITATIONAL ACCELERATION. The weight of an object on the other hand takes GRAVITY in consideration. Also, the amount of MATTER consisting of atoms and/or (solely) elementary particles. The atomic standard with respect to mass uses the “unified atomic mass unit” u defined as $1\ u = 1/12(^{12}\text{C})$, one-twelfth of the mass of a standard carbon ATOM (^{12}C). Mass operational definition relies on the derived quantity of matter (m) based on the measured weight (force “ F ”) and the known gravitational acceleration (a) at the location of the measurement, leading to the mass by applying NEWTON’S SECOND LAW: $F = ma$.

Mass (mu)

[atomic, nuclear] A unit of mass based on the elementary atomic building blocks, using 1/16 of the mass of an oxygen ATOM, where the oxygen atom has a mass of 16.00000 mu. Abbreviation: mu, also found as “atomic mass unit,” amu.

Mass absorption coefficient

[nuclear] See MASS ATTENUATION COEFFICIENT.

Mass attenuation coefficient (μ/ρ)

[biomedical, energy, nuclear] Measurement of the DECAY in PHOTON stream for an ELEMENT, chemical species, or substance (e.g., SOLUTE) due to annihilation or SCATTERING of ELECTROMAGNETIC RADIATION at a particular wavelength; defined per unit mass (based on density $\rho = m/V$, where m is the mass of the substance with V ; note gaps in the substance will reduce the PROBABILITY of interaction with EM waves and hence reduced density results in lower attenuation) for a single mixture or element.

Mass balance

[thermodynamics] See CONSERVATION OF MASS.

Mass balance equation

[thermodynamics] Expression that states that the quantity of all species in a medium (solid, LIQUID, and SOLUTION) containing a particular ATOM (in stable or ionized state or bound as molecules or group of atoms) must equal the quantity of that constituent (e.g., ions or group of atoms: molecules) that has been delivered to the medium. This can be expressed in moles or grams. In a chemical reaction, the mass balance equation defines the quantities of the species involved in the reaction, for instance $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \rightleftharpoons 2\text{H}^+ + 2\text{OH}^-$.

Mass balance for a work, heat, and bulk-flow process

[thermodynamics] Kinetic process with respect to the relative MOTION of chemical constituents of various species with respect to each other (i.e., separation and mixing processes). The end result is driven by concentration gradients, which are represented by the entropy of the imbalance in chemical potential. Fluid flow without mass transfer falls under FLUID mechanics, and is not part of the field of mass transfer. Mass transfer theory closely resembles HEAT TRANSFER, as described by the pioneering work of Lewis and Whitman in 1924. The mass transfer in analogy uses a mass transfer coefficient h_m , equivalent to the thermal convection coefficient h . DIFFUSION theory may only be applied for molecular mixtures; PARTICLE size ($d < 10^{-8}\ m$). Under colloid solutions and suspensions (particle size ranging: $10^{-8}\ m < d < 10^{-5}\ m$) the Brownian theory applies. For larger particles ($d > 10^{-5}\ m$), the movement/migration is described by NEWTONIAN MECHANICS. Rewriting Fick’s law for mass diffusion (without phase changes or chemical reactions), this provides for the constituent i : $(\partial \rho_i / \partial t) + \nabla \cdot (\rho_i \vec{v} + \rho_i \vec{v}_{di}) = (\partial \rho_i / \partial t) + \nabla \cdot (\rho_i \vec{v}) - D_i \nabla^2 \rho_i \vec{v} + \rho_i \vec{v}_{di} = \vec{w}_i$, where ρ_i is the density

of the respective species (in the thermodynamic equivalent the density can be replaced by a temperature parameter), $\vec{v}_{d,i}$ the diffusion velocity for constituent i , $\vec{v}$ the convection velocity, D_i the respective DIFFUSIVITY for the constituents ($[(dn_{di}/dt)/A]\vec{n} = -D_i\nabla c_i$, where n_{di} is the mass diffusion FLUX of species i , A the cross-sectional area of mass transfer, c_i the respective concentrations for the chemical constituents [mol/m^3], and $\vec{n}$ the normal to the surface area), and $\vec{w}_i$ the FLOW rate (particle flux).

Mass damper

[general, mechanics] Dampening pod attached to a moving mass, for example a SHOCK ABSORBER. Also known as a “harmonic absorber,” based on the capacity of changing the AMPLITUDE and RESONANCE FREQUENCY of a FORCED OSCILLATION. The mass damper usually includes a spring for ENERGY conversion purposes. The damper is usually attached to a solid structure to reduce the dynamic response of the oscillating structure. The frequency of the damper can be tuned to a particular oscillation frequency to optimize the dampening efficiency. Tuning to specific structural frequency can be accomplished by the FRICTION forces applied within the dampener as well as the spring constant. Dampening can be accomplished by means of FLOW constraints of a liquid filled piston system or by means of surface contact friction. Mass dampers are used in tall buildings, especially in earthquake-prone zone, to reduce the vibrations from wind and tremors and preserve the integrity of the structure (see Figure M.49).

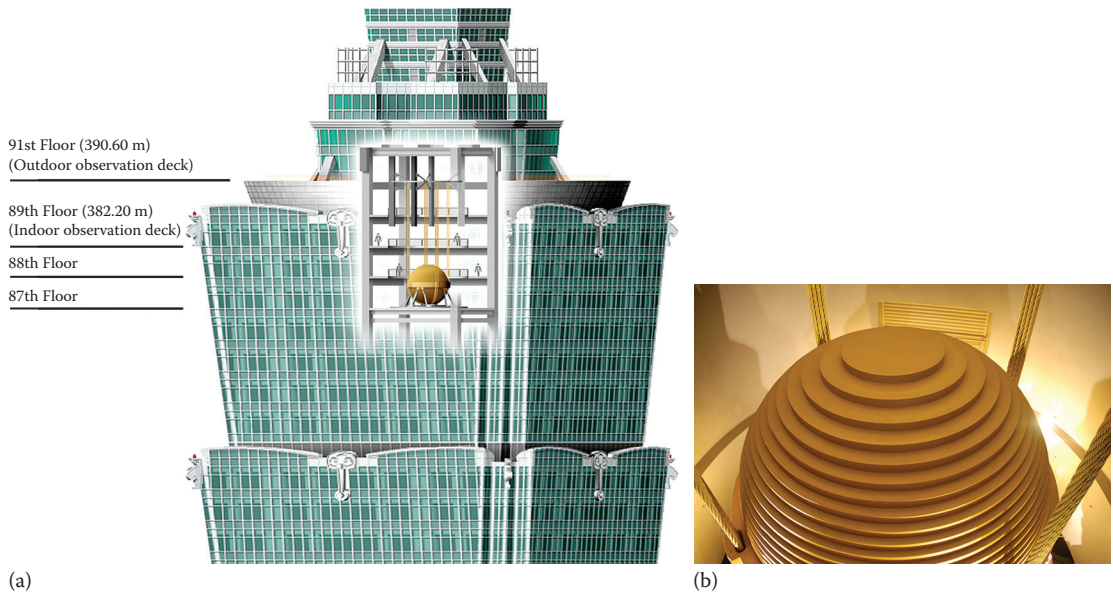


Figure M.49 (a) Tuned Mass damper in sky-scraper in Taipei; Taipei 101 and (b) detail of the Taipei AMss damper. (Courtesy of Guillaume Paumier.)

Mass defect

[chemical, general, nuclear] In chemical and atomic systems this relates to the mass change in bound systems (primarily decrease), particularly with respect to atomic nuclei. The mass nuclear defect can be expressed as $\Delta m = Z(m_p + m_e) + (A - Z)m_n - m_{\text{atom}}$, where m_{atom} is the mass of the primary nuclide, A the mass number (representing the number of nucleons), Z the atomic number (representing the number of protons), m_p , m_e , and m_n , respectively the PROTON, electron, and NEUTRON mass.

Mass density (ρ)

[solid-state] MASS (m) per unit volume (V): $\rho = m/V$, also DENSITY.

Mass energy

[nuclear] Concept that the MASS (m) of an object or system has an ENERGY (E) equivalent: $E = mc^2$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light. Additionally, adding for instance 180 megajoules (180 MJ) of a variety of energy formats to an object will increase the mass by 2 μ g. Conversely, mass can be converted into energy, such as with the ATOMIC BOMB or nuclear power generators.

Mass energy absorption coefficient

[biomedical, energy, thermodynamics] The X-RAY energy (keV–MeV range) absorbed per unit mass as described in RADIATION THERAPY treatment, also referred to as mass–energy attenuation (μ_{en}/ρ). The mass–energy attenuation coefficient cannot directly be derived; however, it relies on the theoretical conversion with respect to the mass attenuation coefficient provided by an efficiency factor f_s ; after Stephen M. Selzer (1940?–) who provided the heuristic proof of the relationship between the radiation MASS ATTENUATION COEFFICIENT (μ/ρ) and the MASS ENERGY transfer coefficient (μ_{tr}/ρ): $\mu_{\text{en}}/\rho = (\mu_{\text{tr}}/\rho)(1 - g_r) = f_s (\mu/\rho)(1 - g_r)$, where the average ratio of kinetic energy of particles ionized during radiation interaction and lost due to deceleration with inherent emission of PHOTON (i.e., radiative DECAY) is represented by g_r .

Mass excess

[nuclear] Expression of the BINDING ENERGY between nuclides (i.e., NUCLEAR BINDING ENERGY), in relative measure to the binding energy within the carbon-12 ATOM characterized per nucleon. In a nuclide, this represents the difference between the actual mass of the nuclide with respect to the mass number expressed in atomic mass units.

Mass flux

[general] The FLOW rate of mass per unit area. The following symbols are used in different fields of science and ENGINEERING: ϕ , Φ , j , J . One specific example is the current density (electron flow rate per cross-sectional area, but as positive particles) often shown as j or J .

Mass number (A)

[atomic, chemical, general, nuclear, solid-state] The number of nucleons in the NUCLEUS of an ATOM. Symbol: A .

Mass of the neutron

[nuclear] Neutral charge nuclide with mass $m_p = 1.674929 \times 10^{-27}$ kg = 1.00866 u.

Mass spectrograph

[atomic, general, solid-state] See MASS SPECTROMETER and MAGNETIC SPECTROMETER.

Mass spectrometer

[atomic, general, solid-state] Device used to separate accelerated ions with respect to their respective CHARGE (q) to MASS (m) ratio: q/m . Charges are first accelerated under an applied electric field (E as the result of a POTENTIAL DIFFERENCE over a fixed DISTANCE, providing a Coulomb force $F_{\text{Coulomb}} = qE$) and are next sent through a velocity (v) filter (based on sending accelerated ions through a MAGNETIC FIELD (B); $qE = qvB$, yielding: $v = E/B$) that provides a uniform velocity profile, irrespective of charge or mass. The ions with specific mass (m) and CHARGE (q) will be diverted by means of an external uniform magnetic field (B_0), providing a radius of curvature ($R_{\text{Mass-Spec}}$) of the circular trajectory under the right-hand rule resulting from the magnetic force $F_{\text{mag}} = q\vec{v} \times \vec{B}$: $q/m = E / BB_0 R_{\text{Mass-Spec}}$. Generally the ions have a single charge (positive or negative; $q = |e| = 1.60217657 \times 10^{-19}$ C), but not necessarily. The spectroscopic position of the detection plate (including the detector slit configuration, “mechanically” providing a final filtration mechanism) for the

respective particles with respect to the undeflected ION is $\Delta y = -a_1(\Delta(mv^2)/m_0v_0^2) + a_2(\Delta(mv)/m_0v_0)$, where $m = m_0 + \Delta m$, $v = v_0 + \Delta v$, and a_1 and a_2 are characteristic constants with respect to the design and functionality of the mass spectroscopy instrument.

Mass spectroscopy

[atomic, biomedical, solid-state] Detailed measurement of the MASS (m) of isotopes by a device (MASS SPECTROGRAPH or mass spectrometer) introduced by Francis William Aston (1877–1945) in 1919. Charged particles are performing a curved trajectory with radius depending on their charge and mass. The deflection is based on $qE = mv^2/2$, CONSERVATION OF ENERGY, where q is the net ISOTOPE charge, E is the applied electric field, and v is the achieved velocity of the accelerated PARTICLE under the influence of the force. A MAGNETIC deflector separates the particles based on their trajectory and are sent through slits, providing a discrete location of the various isotopes with respective masses. The RESOLVING POWER of the device is defined by the design and the focusing ability of the spectrometer (see Figure M.50).

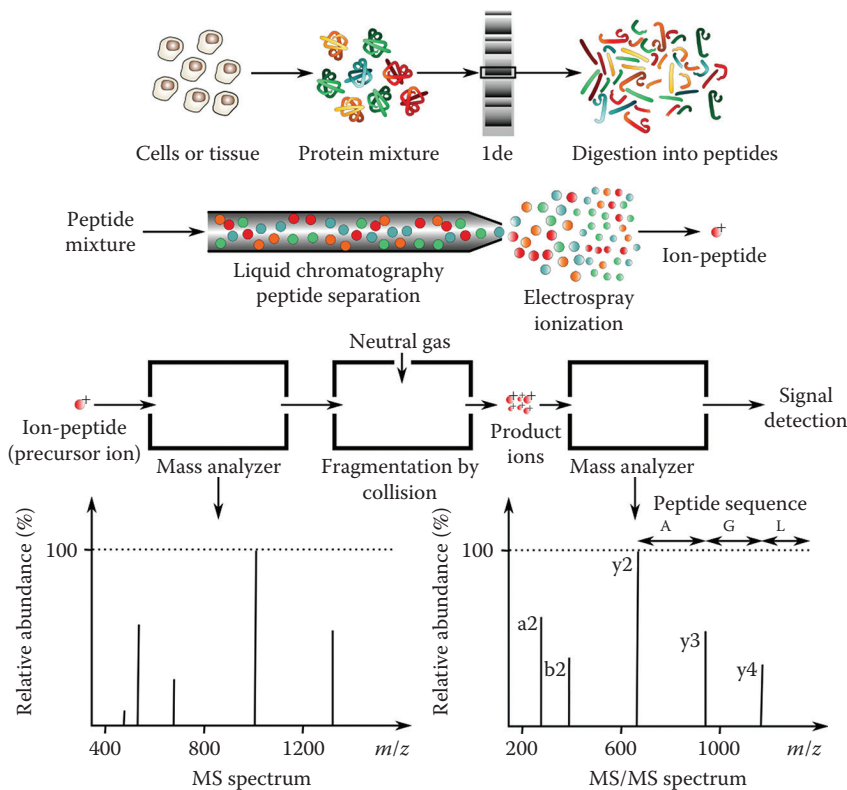


Figure M.50 Mass spectroscopy.

Mass–spring system

[acoustics, biomedical, general, mechanics, nuclear] {use: energy conversion, actuation, imaging} There are many mass–spring systems, some even damped. To name but a few: shock absorbers on an automobile, woofer (loud SPEAKER), gong/bell, tooth brush, and many more. Generally a simple mass–spring system obeys FICK'S LAW. A damped mass–spring system uses some form of COMPLIANCE with a phenomenological constant identifying the level of “RESISTANCE” ($C_{\text{Compliance}}$) to dampen the MOTION. Examples of damped motion are shock absorbers, woofer loud speaker cone, and keys on a PIANO. Several motions are repetitive with a constant frequency and are considered damped OSCILLATIONS, other movements are single pulse. All motions rely on an external force or driving mechanism to initiate the motion. The force

expression for a damped spring motion is $F = F_{\text{external}} - C_{\text{compliance}}v - kx = ma$, where v is the VELOCITY of the mass. The external force resulting from a blow (SHOCK ABSORBER or piano) is the change in MOMENTUM P_m : $F_{\text{external}} = (dP_m/dt) = m(dv/dt)$, or it can be a driving mechanism based on ELECTRICITY or MAGNETISM with a preset frequency (e.g., VOICE COIL), another application is in ULTRASOUND imaging using piezoelectric or other mechanisms of driving the OSCILLATION (*also see* OSCILLATION) (see [Figure M.51](#)).

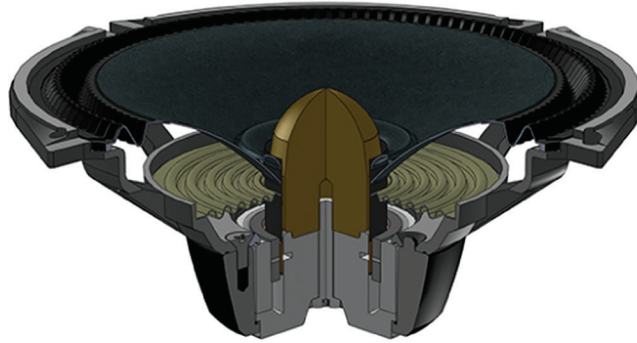


Figure M.51 Mass-spring system that is, loud speaker.

Mass transfer Biot number (Bi_{mass})

[fluid dynamics] Ratio of diffusive to reactive, respectively convective mass transfer resistance:

$Bi_{\text{mass}} = k_f L / D_{\text{solid}} = h_D L / D_{\text{solid}}$, where k_{fb} is the THERMAL CONDUCTIVITY, D_{solid} is the DIFFUSION coefficient, L is the characteristic length, and h_D the mass-transfer coefficient. The Biot mass transfer number determines the uniformity of constituent concentration in solids.

Mass transfer Fourier number

[thermodynamics] See **FOURIER NUMBER**, **MASS TRANSFER**.

Mass transformation equation

[atomic] Relativistic MASS (m) of an object traveling with velocity v in the observer's frame:

$m = m_0 \left(1 / \sqrt{1 - (v^2/c^2)} \right)$, where $c = 2.99792458 \times 10^8$ m/s is the speed of light in vacuum and m_0 is the REST MASS (classical mechanics). The coefficient $\left(1 / \sqrt{1 - (v^2/c^2)} \right)$ is defined as the mass transfer coefficient.

Mass absorption coefficient

Massieu, François Jacques Dominique (1832–1896)

[thermodynamics] Scientist and engineer from France. Massieu is known both for his introduction of the “characteristic function” of a FLUID body, the MASSIEU FUNCTION, and the initial thermodynamic concept of the MASSIEU POTENTIAL, defining the free entropy of a system (see [Figure M.52](#)).



Figure M.52 François Jacques Dominique Massieu (1832–1896).

Massieu function

[thermodynamics] Description of the entropy of a system based on a coordinate system with a number (n) of axes {cumulative: (x_i, y_j) } that correlate to the respective variables of the system: $[\Psi] = \Psi(X_1, X_1, \dots, X_i, Y_{i+1}, \dots, Y_n)$, introduced in 1869 by FRANÇOIS MASSIEU (1832–1896) (see MASSIEU POTENTIAL).

Massieu potential

[thermodynamics] Entropic thermodynamic potential defined as $\Phi = S - (1/T)U$, where $S = (U/T) + (PV/T) + \sum_{i=1}^n (-\mu_i(N_i/T))$ represents the entropy of a system, T the temperature, U the internal ENERGY, P pressure, V the volume of the system, μ_i the chemical potential chemical constituent i , and N_i the quantity of items (particles, atoms, ions, etc. expressed in MOLE) of chemical component i . The concept of free entropy as introduced by FRANÇOIS MASSIEU (1832–1896) in 1869. The Massieu potential and free energy predate the Gibbs's free energy, which was introduced in 1875 by JOSIAH WILLARD GIBBS (1839–1903). It was shown that the free entropy follows from the LEGENDRE TRANSFORM of the true entropy of a system or process. The Massieu potential is based on the fact that the state of a body is completely defined when two of the three parameters that represent the volume of the system, the temperature of the system, as well as the pressure on its surface are known. Also known as Helmholtz free entropy.

Material fatigue

[general, mechanics] Localized gradual structural damage to a composite or metallic structure or material resulting from cyclic or infrequent repetitive loading. The FATIGUE results from applied nominal maximum stress below the ultimate TENSILE STRESS of the material, and generally less than the yield stress limit. When a certain stress threshold is exceeded, on a MICROSCOPIC level, certain threshold, cracks will form, weakening the

integrity of the structure on a macroscopic scale. The continued exposure to the forces involving the implementation of material fatigue will eventually result in breakage (*also see* METAL FATIGUE) (see [Figure M.53](#)).



Figure M.53 The impact of Material Fatigue on the structural integrity of the Tacoma Narrows Bridge in 1940, constructed of metal, concrete, and asphalt. The bridge was destroyed only weeks after the official opening due to the vibrations on the suspension cable (Aeolian sound wave) providing the resonance frequency of the road-surface section aspect of the bridge with the associated natural frequency based on elastic moduli, characteristic lengths, and persistence in driving wind (direction and magnitude).

Matter

[general, nuclear, solid-state] Compilation of the physical properties of a medium that define its response to external influences, specifically force. Matter is congealed from a mixture of ELEMENTS for which the atoms and molecules are held together by short- and long-range forces such as gravitational attraction and van der Waals attraction. Matter can be found in various states, or phases: GAS/VAPOR, LIQUID, solid and PLASMA. Mass is a quantity of MATTER, one of the fundamental dimensions, next to thermal properties and volume (incorporating the dimensions of all directions within the frame of reference), and hence density. The thermal properties are internal ENERGY and heat, next to the SPECIFIC HEAT with respect to phase transfers, the change of phase and the pattern in which this takes place, heat exchange with neighboring bodies, conduction, convection, and radiation next to THERMAL EXPANSION. Additional mechanical properties of

matter are deformation, COMPLIANCE, and MOMENT OF INERTIA, depending on the mass distribution and applicable LATTICE and/or crystalline structure (see [Figure M.54](#)).

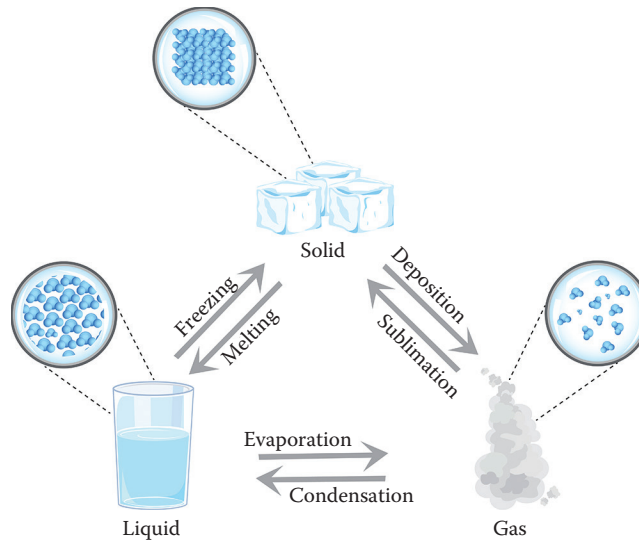


Figure M.54 Matter concepts.

Matter wave

M

[acoustics, general] Wave propagation based on mechanical disturbance of particles in a medium. Also referred to as a MECHANICAL WAVE, primarily pertaining to ACOUSTICS and FLOW (crest of waves on beach). The VIBRATION of a string on an instrument is a transverse matter wave, and the SOUND of a VOICE in AIR is a longitudinal matter wave (*also see* **DE BROGLIE**) (see [Figure M.55](#)).



Figure M.55 Matter wave in flag.

Maupertuis, Pierre Louis Moreau de {Pierre Louis Moreau de Maupertuis} (1698–1759)

[computational, general] French mathematician and physicist. Maupertuis formulated the rudimentary principle of the path of least RESISTANCE to CONSERVE ENERGY (see Figure M.56).



Figure M.56 Pierre Louis Moreau de Maupertuis (1698–1759).

Maupertuis principle

[computational, general] Integral equation describing the path of a PARTICLE in MOTION, following the path of “least action,” that is, path of least RESISTANCE; introduced by PIERRE LOUIS MOREAU DE MAUPERTUIS (1698–1759). The integral defines the condition of the extremum (maximum, minimum, saddle point, or stationary point) for a system with N generalized coordinates $\vec{\chi} = (\chi_1, \chi_2, \dots, \chi_N)$ between two states referenced as χ_1 and χ_2 , both as a function of location, conditions (outlined by the conjugate momenta at the generalized coordinates of the system: $\vec{p} = (p_1, p_2, \dots, p_N)$) and TIME (t) by means of the action functional using the path as a function to define the location of the extremum, that is, the condition of the function describing the system: $S_0[\vec{q}(t)] \stackrel{\text{def}}{=} \int \vec{p} \cdot d\vec{q}$ which yields a SCALAR as a solution, where $p_i \stackrel{\text{def}}{=} [\partial L(\vec{\chi}, \vec{\dot{\chi}}, t)] / \partial \dot{\chi}_i$, $L(\vec{\chi}, \vec{\dot{\chi}}, t)$ the Lagrangian of the system, describing the first-order perturbations of the system. The perturbation does generally not exceed the second-order changes in the “path” $S_0[\vec{q}(t)]$.

Maximum occupation number

[high-energy, quantum, solid-state] Ground-state ENERGY EIGENVALUE configurations per unit volume for a FERMION collective in a medium (i.e., condensate) consisting of millions of atoms. The primary difference between fermions and bosons is that fermionic energy states have a maximum occupation number of 1. Bosons, on the other hand, in theory have unlimited occupation states. The Pauli principle for the constituent fermions would practically limit the BOSON occupation number. The maximum occupation number is

expected to be proportional to the “volume” available to the bosons, divided by the volume occupied by the number of fermions constructing one boson (see [Figure M.57](#)).

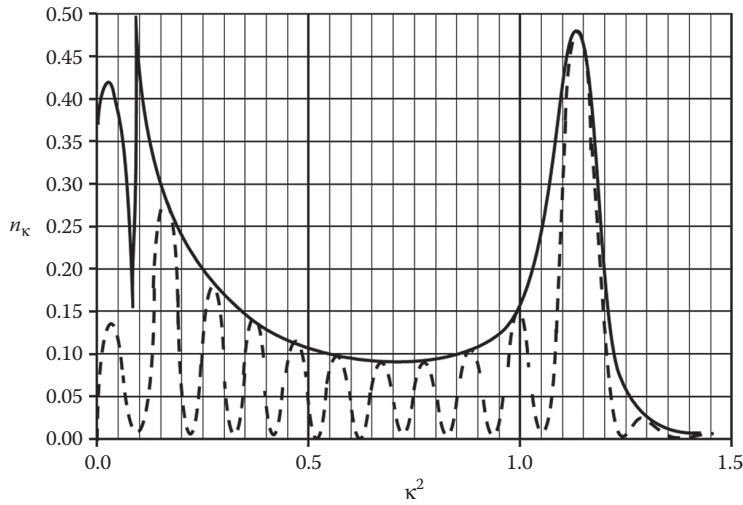


Figure M.57 The maximum occupation number is outlined by the contour of the actual occupation numbers (n_k) (dotted line) in the excitation band of fermions excited (“pre-heated”) to $\lambda\phi^4$ –inflation (ϕ the oscillation) at resonance under the condition $q \equiv (h^*/\lambda) = 1$, λ the oscillation wavelength. The boundary conditions are defined by the Fermi sphere with radius $\kappa_F = q^{1/4}m_\phi$, m_ϕ the inflation mass of the system, $q = h^{*2}\phi_0/m_\phi^2$, h^* the coupling between the inflation and the fermions (Yukawa type—coupling) and ϕ_0 the amplitude of the inflation oscillation. The resonance in this case has 10 background oscillations.

M

Maxwell, James Clerk (1831–1879)

[electromagnetism, general] Scottish scientist and physicist who developed a rigorous relationship between changing MAGNETIC phenomena and the resulting varying electric manifestations such as the induced electromotive force electric potential in a closed circuit, or an alternating electric field in a more general concept. The work of Maxwell was based on the efforts by the American scholar JOSEPH HENRY (1797–1878), the English scientist MICHAEL FARADAY (1791–1867), as well as inspired by CHARLES WHEATSTONE, WILLIAM THOMSON (i.e., Lord Kelvin), the work by CARL FRIEDRICH GAUSS (1777–1855), and ANDRÉ MARIE AMPÈRE’S (1775–1836) circuital law, compiled shortly after his graduation from the University of Cambridge in 1854 (see [Figure M.58](#)).

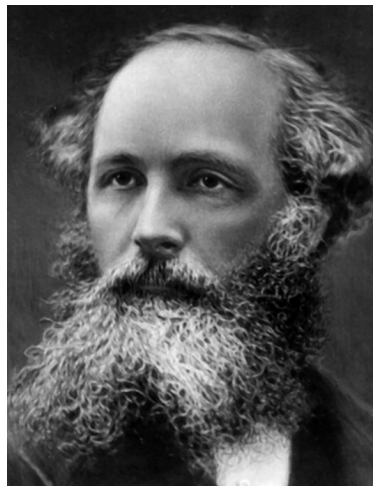


Figure M.58 James Clerk Maxwell (1831–1879).

Maxwell equations

[energy, optics] philosophical extension of the concepts of Faraday's law pertaining to the interaction of a varying MAGNETIC FIELD and the ensuing alternating electric field and, when appropriated, the associated electromotive force. In the 1820s, the efforts of both the English scientist MICHAEL FARADAY (1791–1867) and the American scholar JOSEPH HENRY (1797–1878) independent of each other provided the theoretical support for JAMES MAXWELL CLERK (1831–1879) to develop theoretical expressions linking magnetic field variations to electric field changes developing several theories of electromagnetic WAVE propagation and in the process underwriting the propagation of electromagnetic waves at the speed of light. The Maxwell equations are the following:

ORIGIN	DIFFERENTIAL EQUATIONS IN VACUUM	INTEGRAL EQUATIONS IN VACUUM
Gauss's law	$\nabla \cdot \vec{E} = 4\pi\rho_e$	$\oint_S \vec{E} \cdot \vec{n} dA = -4\pi \oint_V \rho_e d^3r = Q_{in}/\epsilon_0$
Gauss's law for magnetism	$\nabla \cdot \vec{B} = 0$	$\oint_S \vec{B} \cdot \vec{n} dA = 0$
Faraday's law	$\nabla \times \vec{E} = \partial \vec{B} / \partial t$ $\partial \vec{E} / \partial z = 0$	$\oint_S \vec{E} \cdot \vec{n} d\ell = -(1/c)(\partial / \partial t) \oint_V \vec{B} \cdot \vec{n} dA$
Ampère's law	$\nabla \times \vec{B} = \epsilon_0 \mu_0 (\partial \vec{E} / \partial t)$ $= \nabla \times \vec{B} - (1/c^2)(\partial \vec{E} / \partial t)$ $= (4\pi/c) \vec{J}$	$\oint_S \vec{B} d\ell = -\oint_V \left((4\pi/c) \vec{J} + (1/c)(\partial \vec{E} / \partial t) \right) \cdot \vec{n} dA$

Where $\vec{E}$ is the electric field, ρ_e the charge density per unit volume V , t is time, $\vec{J}$ is the current density, $c = \sqrt{\epsilon_0 \mu_0}$ the speed of light, $\vec{n}$ the normal to the surface A of the enclosed space, S the perimeter of the enclosed surface, ℓ the length of the loop enclosing the charges, respectively, $d\ell$ the segment of the tangent length to the curve of the loop, r the radius of the loop, $\mu_0 = 1.2566 \times 10^{-6} (\text{Wb/A.m}) (\text{N/A}^2)$ the DIELECTRIC permeability for VACUUM, $\epsilon_0 = 8.8541878 \times 10^{-12} (\text{C}^2/\text{Nm}^2)$ the dielectric permittivity for vacuum, Q_{in} the enclosed net total charge, ϵ_0 the dielectric permittivity of vacuum, and $\nabla = \partial / \partial x_i$ is the Laplace operator with respect to all DEGREES OF FREEDOM x_i . Analogously for a magnetic field ($\vec{B}$), the ELECTROMAGNETIC FIELD parameters are related by the Lorentz force on a moving point charge q : $F_\ell = q(\vec{E} + (v/c) \times \vec{B})$, with v the velocity of the moving charges. The current density is connected to the charge change rate as $(\partial \rho_e / \partial t) + \nabla \cdot \vec{J} = 0$.

Maxwell–Boltzmann distribution ($f(X)$)

[fluid dynamics, general, mechanics] Distribution of physical property (e.g., velocity and ENERGY) based on the theoretical work by JAMES CLERK MAXWELL (1831–1879) and LUDWIG EDUARD BOLTZMANN (1844–1906) defined as follows. For the Maxwell energy distribution $N_i/N = g_i e^{-(E_i/k_b T)} / \sum_j g_j e^{-(E_j/k_b T)}$,

where i represents a specific MICROSTATE (e.g., QUANTUM STATE), E_i represents the energy of a specific isolated microstate, T the temperature, $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ is the BOLTZMANN CONSTANT, g_i a factor that defines the number of microstates with the same energy (DEGENERACY factor), N_i the number of molecules in one equilibrium microstate, and N the total number of molecules this yields: $f(E)dE = 2(1/k_b T)^{3/2} \sqrt{(E/\pi)} e^{-(E/k_b T)} dE$. For the momentum ($p = mv$) (i.e., velocity) this writes as $N_i/N = g_i e^{-((p_{i,x}^2 + p_{i,y}^2 + p_{i,z}^2)/2mk_b T)} / \sum_j g_j e^{-(E_j/k_b T)} = (1/Z) \exp[-((p_{i,x}^2 + p_{i,y}^2 + p_{i,z}^2)/2mk_b T)]$ where m is the molecular mass for the respective constituent of the gas with distribution function $f(p)dp = (1/(2\pi mk_b T))^{3/2} e^{-((p_x^2 + p_y^2 + p_z^2)/2mk_b T)} dp$ (see Figure M.59).

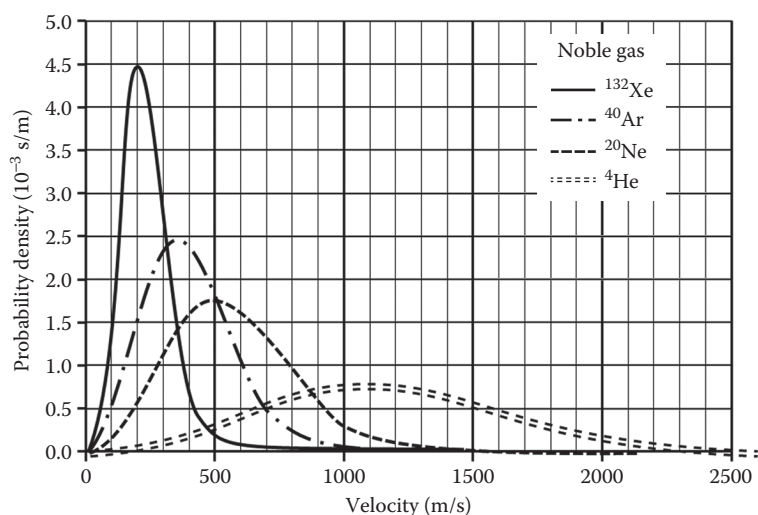


Figure M.59 Outline of the Maxwell–Boltzmann distribution.

Mayer, Julius Robert von {Julius Robert von Mayer} (1814–1878)

[general, nuclear, thermodynamics] Physicist and physician from Germany, pioneer in thermodynamic relations (see VON MAYER, JULIUS ROBERT) (see Figure M.60).



Figure M.60 Julius Robert von Mayer (1814–1878).

Mayer, Maria Goeppert (Göppert) (1906–1972)

[atomic, computational, general, nuclear] Mathematician, scientist, and physicist from Germany at the time, now Poland. Maria Goeppert-Mayer provided pivotal elaborations on the BOHR ATOMIC MODEL for which she received the Nobel prize in 1963. Maria's contemporaries and friends included her teacher MAX BORN (1882–1970) and friend NIELS BOHR (1885–1962). Additional work of Maria included uranium ISOTOPE separation during the Second World War. Also known as Goeppert-Mayer, Maria (see [Figure M.61](#)).



Figure M.61 Maria Goeppert-Mayer (1906–1972).

Mayer relation

[nuclear, thermodynamics] Correlation between the SPECIFIC HEAT under constant pressure (c_p) to that under constant volume (c_v), derived by JULIUS ROBERT VON MAYER. The relationship is a function of the coefficient of isothermal compressibility (κ_T) and the coefficient of isobaric expansion (α_p) next to the TEMPERATURE (T) and VOLUME (V) as $c_p = c_v + (T\alpha_p^2 V / \kappa_T)$.

Mclean, Jay (1890–1957)

[biomedical, fluid dynamics] Physician, chemist, and scientist from the United States. The collaborative efforts of Jay McLean and his professor WILLIAM HENRY HOWELL (1860–1945) resulted in the definition of the anticoagulant properties and the clinical and hemodynamic impact of heparin in 1916 (see [Figure M.62](#)).



Figure M.62 Jay McLean (1890–1957). (Courtesy of the US National Library of Medicine; donation by Dr. Brockbank 1956.)

McLennan, John Cunningham, Sir (1867–1935)

[atomic, nuclear] Scientist and physicist from Canada. Colleagues and collaborators John McLennan and Eli Franklin Burton (1879–1948) discovered a new form of RADIOACTIVITY, consisting of man-made radiation (produced in a VACUUM tube with an electron beam, creating metallic origin radioactivity) that had a high-penetration ability and was ionizing in nature in around 1902. Additional pioneering work by Sir McLennan was in the LIQUEFACTION of helium (see [Figure M.63](#)).



Figure M.63 Sir John Cunningham McLennan (1867–1935) in 1935. (Courtesy University of Toronto, Toronto, Canada.)

Mean free path

[atomic, computational, fluid dynamics, mechanics, nuclear, optics] The average DISTANCE of the resultant vector that describes the path that a particle or ENERGY unit (i.e., PHOTON) moves between interactions that alter the vector magnitude and or direction (e.g., collisions): $\delta = \sum_N \ell_i / N$, for a GAS $\text{mfp} = \lambda_{\text{mfp}} = RT / (\sqrt{2}) \pi d^2 N_A P$, $R = 8.3144621(75) \text{ J/Kmol}$ the universal gas constant, T = temperature, d = diameter of vessel/container (i.e., characteristic length), $N_A = 6.02214129(27) \times 10^{23} \text{ mol}^{-1}$ (Avogadro's number), and P the pressure of the gas. Also, the mean distance (i.e., PROBABILITY of the occurrence of traveling this hypothetical distance, expressed by the resultant vector) a photon traverses between optical interactions of either SCATTERING (e.g., atomic resonance) or annihilation (absorption). Abbreviation: mfp, symbol, δ (see Figure M.64).

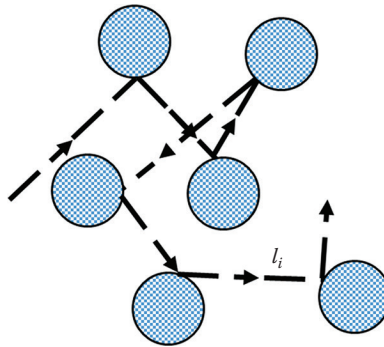


Figure M.64 Representation of the mean-free-path in multiple interactions.

Mean life (τ_{decay})

[atomic, nuclear] See MEAN LIFETIME.

Mean lifetime (τ)

[general, nuclear] Mathematical average lifetime of the state of an ISOTOPE in a medium consisting of radioactive material. Also, the exponential constant that defines the DECAY of isotope defined as the reciprocal of the decay constant expressed as $\tau_{\text{decay}} = 1/\lambda_{\text{decay}}$, where $dN/dt = -\lambda_{\text{decay}} N$ with N the number of radioactive isotopes, yielding $N(t) = N_0 e^{-t/\tau_{\text{decay}}}$. This expresses the fact that τ_{decay} is the time in which the quantity of isotopes reduces to $e^{-1} = 0.3679$, or 37% (also see HALF-LIFE).

Mean Speed Theorem

[general] See MERTON MEAN SPEED THEOREM.

Mean value of potential over a spherical surface

[computational, electromagnetism, fluid dynamics] In electric applications, this pertains to the surface charge on a spherical CONDUCTOR. Note that the charge will be equally distributed over the surface (S) of the conductor with surface charge density σ_{charge} . The sphere will have a radius $r > 0$. The total charge is defined as $q_{\text{electric}} = A\sigma_{\text{charge}} = 4\pi r^2 \sigma_{\text{charge}}$. Since this is a symmetric condition, the electric field is directly proportional to the DISTANCE to the origin of the sphere R . The electric potential is derived from the Coulomb law: $V(R) = \oint (\sigma_{\text{charge}} / 4\pi\epsilon_0 r') dr'$, where ϵ_0 is the DIELECTRIC permittivity of VACUUM. Additionally GAUSS'S LAW provides $V(R) = q_{\text{electric}} / 4\pi\epsilon_0 R$. Equating the two potentials yields that the potential outside the sphere is equal to the potential at the center of the sphere: $V(R) = q'_{\text{electric}} / 4\pi\epsilon_0 r$, where q'_{electric} is the total enclosed charge, assuming the sphere is the only charged volume in the space under consideration. In FLUID DYNAMICS,

the potential pertains to the VELOCITY POTENTIAL (ϕ_{flow} ; *Note:* $v_x = \partial\phi_{\text{flow}}/\partial x$, etc. and $v_R = \partial\phi_{\text{flow}}/\partial R$) expressed by $M(R) = (1/4\pi r^2) \oint_S \phi_{\text{flow}} dS = (1/4\pi) \oint_0^{4\pi} \phi_{\text{flow}}(r, \omega) d\omega$, where ω represents the SOLID ANGLE over the surface of the sphere. Incompressible fluids can be described as having potential flows that are solutions of the NAVIER–STOKES EQUATIONS. In solving for the potential flows, one can apply the HELMHOLTZ DECOMPOSITION principle, which states that every solution of the NAVIER–STOKES equations can be decompartmentalized in respective rotational parts and irrotational components, each satisfying LAPLACE’S EQUATION. The irrotational part will satisfy the boundary conditions, whereas the rotational velocity will generally not.

Measurement

[general] Acquisition of data pertaining to an event, phenomenon, or object (dimensions, weight, etc.) in relation to establishing the parameters that best describe the occurrence using qualified and calibrated equipment best suited for the determination of the designated parameters.

Mechanical energy

[biomedical, general, mechanics] *See* WORK.

Mechanical wave

[engineering, general, geophysics] Wave produced by the displacement of material. A mechanical wave can be longitudinal, as performed by the compression of AIR in ACOUSTIC WAVES, or by transverse displacement, such as the plucking of a string on a string instrument (e.g., GUITAR, harp, and PIANO). A combination wave with both transverse and longitudinal properties can for instance be an EARTHQUAKE: combination S-wave and P-WAVE. In SEISMOLOGY, SURFACE WAVES are generally shear waves or TRANSVERSE WAVES, whereas in the core shear waves are not feasible and elastic compression is the main mode (see [Figure M.65](#)).



Figure M.65 Mechanical wave in ropes.

Mechanics

[biomedical, energy, engineering, nuclear, mechanics] The study of objects in MOTION. The motion is for instance, but not limited to, VIBRATION of a chime or cymbal, rotation of a curved billiard ball, as well as a spinning top, and the trajectory of a flare.

Mechanoreception

[biomedical, mechanics] Biological sensing mechanism of action that provides the fundamental basis for touching, HEARING, changes in posture, changes in external or internal pressure, and general strain (biting with the jaw, bending a joint, etc.). The mechanoreception takes place on a cellular level. In the mammalian skin, there are four different types of mechanical sensor: Meissner corpuscles, Merkel disks, Pacinian corpuscles, and Ruffini endings. In the EAR, the ORGAN OF CORTI responds to the bending of a hair to produce an ACTION POTENTIAL that is sent to the brain to indicate the observation of a frequency in the cochlea (BASILAR MEMBRANE) in a specific location that is representative of a single wavelength of motion only. The glabrous SKIN with hair has sensors that respond to stretch. Most knowledge about mechanoreceptor ACTIVITY and function is based on the work by Roland S. Johansson (1950–) and Åke Bernhard Vallbo (1933–), both from Sweden, as recent as the late 1970s (see [Figure M.66](#)).

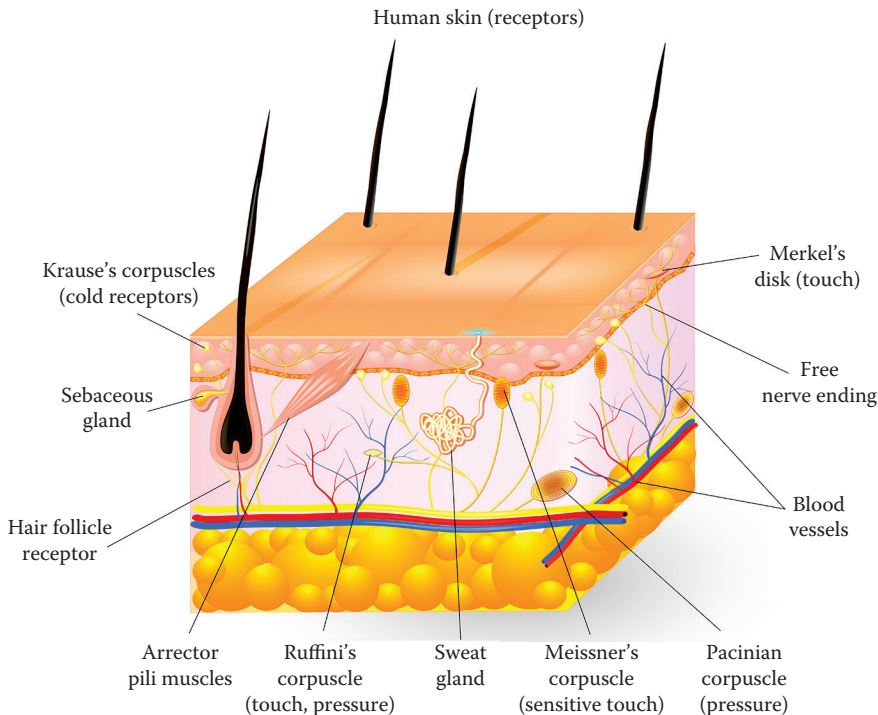


Figure M.66 Examples of mechanoreceptor in human skin.

Mechanosensitive action

[biomedical, chemical, general, thermodynamics] Operation of ION transport mediation in biological cells in response to external influences such as shear, stress, OSMOTIC PRESSURE, GRAVITY, and acoustic MECHANICS. One function in particular, next to sensing of external influences, is the protection of the CELL itself. Sensing the internal cell pressure will result in a pressure regulation mechanism that will ultimately prevent

the cell from bursting. The mechanosensitive action of the cells is mediated by mechanosensitive ion channels (MSCs). These ion channels can currently be subdivided into two groups: (1) responding to fibrous protein and (2) responding to lipid bilayer stress. One measurable effect in response to applied shear and stress in the CELL MEMBRANE is the change in diameter of what is known as the bacterial large mechanosensitive channels (MscL) in the range of 5–6 nm. The Gibbs free ENERGY difference (ΔG) between the open and closed state of the channel (expressed by the cross-sectional area change ΔA) is defined by the lipid bilayer TENSION (T) as $\Delta G = T\Delta A$. Apart from the change in area, there are also changes possible in the shape of the opening, without actual changes to the area. The shape change may provide a preferred vehicle for certain proteins to be transported through the MEMBRANE to act as signaling proteins.

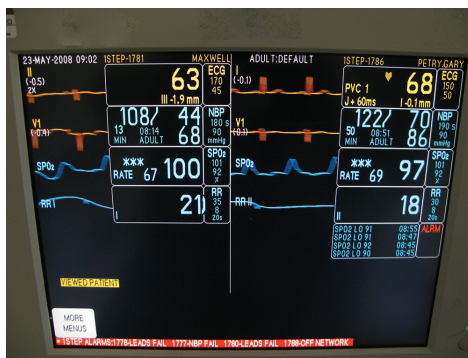
Medicine

[biomedical, electronics, fluid dynamics] Diagnostic and therapeutic modality that uses ENGINEERING and science to either acquire vital signs, produce anatomical and physiological images, or deliver chemical means (therapeutic design for disease treatment), and ENERGY as well as mandates exercise routines to make a best effort in returning the physical condition and vital signs of an individual to established states that are considered within the normal range for a person of a certain AGE, specific sex, and with a general dietary and exercise history, as well as geographical location while also considering potential genetic influences as well as work-place and living condition exposure to the ELEMENTS and foreign materials such as pollution (roughly defined as chemical substances that are not common occurrence or/and have been established as reagents that diminish specific or general levels of physiological, anatomical values, and vital signs). Based on the acquired information, a treatment can be designed to attempt to remove the cause or eliminate the effects of a physical condition, ranging from allergies, fractures, to cancer to the natural phenomenon of childbirth. An additional host of physiological conditions and anatomical conditions are involved in practicing medical science, some are purely chemical in nature based on an imbalance resulting from a broad range of influences, some genetically predetermined, some resulting to exposure to chemicals. Biological systems are integral systems where no single anatomical or physiological aspect stands isolated from all the other activities and conditions in the body and metabolistic activities. Medicine has a long history (dating back thousands of years) that has been influenced by prejudice, lack of diagnostic abilities, as well as generally incomplete information about the physiological integration of contributing factors to a perceived symptom. The multifaceted aspects of engineering (medical device development), drug interaction (chemical design), and psychological integration are only providing major or minor attributes of a complete description for the affliction or the general state of genetic evolution. Even though a broken LEG can be a straightforward cause-and-effect diagnosis with a well-defined treatment modality, the healing

process may not be universal or straightforward (*also see* **BAYESIAN METHODOLOGY**, **BAYES' THEOREM** [i.e., evidence-based medical informatics]) (see [Figure M.67](#)).



(a)



(b)



(c)

Figure M.67 (a) Paramedics acquiring basic vital signs to establish a patient's acute health status, (b) array of vital signs acquired during a medical examination (e.g., HR: hear-rate; BP: Blood-pressure; SPO2: oxygen saturation; and Resp: respiration rate), and (c) alternative medical approach based on acupuncture techniques.

Meissner (Meißner), Walther (1882–1974)

[general] Physicist from Germany. Meissner is best known for his superconductor work, in collaboration with Robert Ochsenfeld (1901–1993) (see [Figure M.68](#)).



Figure M.68 Walther Meissner (Meißner) (1882–1974).

Meissner effect {Meißner effect}

[general] The obliteration of the MAGNETIC FIELD inside a superconductor in comparison to a regular conducting medium. Described in 1933 by the German physicists WALTHER MEISSNER (1882–1974) and Robert Ochsenfeld (1901–1993).

Meitner, Lise (1878–1968)

[atomic, nuclear] Physicist from Austria, famous for her contributions to RADIOACTIVITY and the description of the concept of NUCLEAR FISSION with her nephew Otto Robert Frisch (1904–1979) in 1938. Unfortunately Lise Meitner was not awarded the Nobel prize in Physics for her contributions to the work of FISSION, although her colleague OTTO HAHN (1879–1968) was awarded in 1944 (see [Figure M.69](#)).

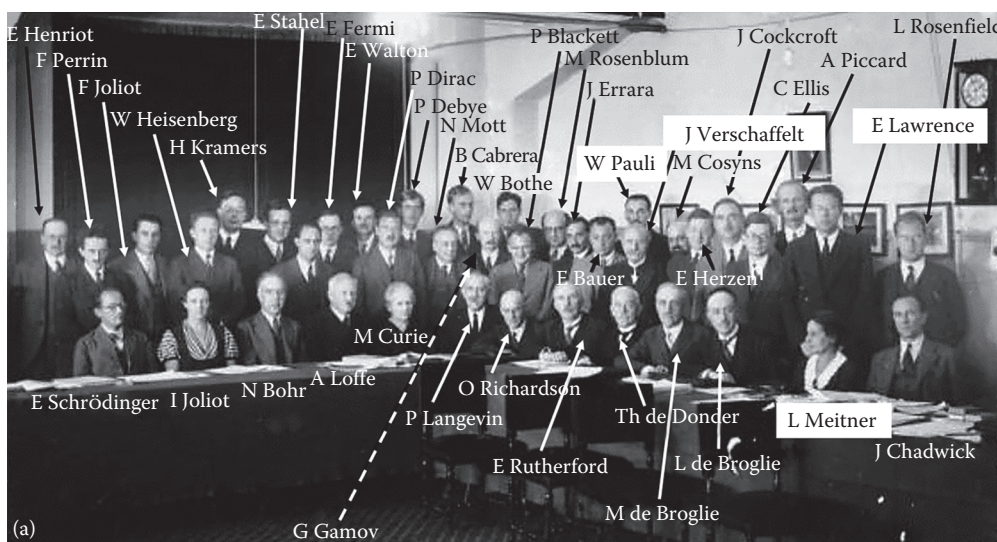


Figure M.69 (a) Lise Meitner (1878–1968) at the 1933 Solvay conference (Structure et propriétés des noyaux atomiques; Structure and properties of the atomic nucleus, under the leadership of Paul Langevin) on the front row, second from the right. Two other notable female physicists represented at this conference are also shown: Marie Curie (1867–1934) and Irène Joliot-Curie (1897–1956). (b) Lise Meitner providing a lecture at the Catholic University in Washington, DC, USA in 1946.

Melting point

[general, thermodynamics] Phase transition TEMPERATURE (T) from solid to LIQUID at a fixed PRESSURE (P) for a constant VOLUME (V) of medium. Phase transition in the opposing direction is referred to as FUSION. For the melting PHASE TRANSITION, the change in Gibbs free ENERGY is zero: $\Delta G = 0$; this provides the condition during melting defined by the ENTROPY (S) as $\Delta S = \Delta H/T$ at constant temperature with H the enthalpy of the system. Under constant temperature, the melting point will be a function of pressure (volume of a solid is fixed), such as the one observed underneath the blade of an ice skater. The melting point can be lowered by the addition of a CHEMICAL COMPOUND, providing “freezing-point depression.” Lowering the melting point will require a lower temperature under constant pressure to achieve melting; hence a solid can be promoted to melt by spreading for instance SALT on ice, as used on roadways during snow storms or FREEZING rain. The melting point as a function of pressure or volume can be found from the PHASE DIAGRAM plot in a pressure–volume curve (PV diagram), or pressure–temperature curve (PT diagram) (*also see* FREEZING POINT *and* FREEZING) (see Figure M.70).



Figure M.70 Melting ice with water with a thermometer indicating 0°C, the melting point for ice.

Membrane

[biomedical, chemical, general] All cells in biological entities are sealed off by a membrane. The membrane provides various functions, ranging from protection of the cellular content, transportation of nutrients (oxygen) and waste, and communication with neighboring cells, to extending its function to acquiring information about the chemical and mechanical circumstances affecting the CELL. The content of the cell is primarily designed to sustain the cell, and supporting a renewable ENERGY source: ATP (ADENOSINE TRI-PHOSPHATE). The CELL MEMBRANE is a hydrophobic lipid bilayer, repelling the water DIPOLE. Membranes are mostly made up of phospholipids such as amino phospholipids, phosphatidylcholine, phosphatidylglycerol, phosphatidylinositol, and sphingomyelins. The phosphatidylinositol structure provides one polar head and two nonpolar lipid chains, with inherent chemical properties. The cell membrane has specific properties related to chemical BARRIERS, chemical transport, and related electric trans-membrane (electric-) potential. The cell membrane is highly permeable to a large selection of hydrophobic molecules, and in particular to lipid-soluble solutes such as ALCOHOL, next to vitamin A and vitamin E, as well as steroids. In contrast, the permeability of water-soluble or hydrophilic molecules is restricted to mainly small molecules only. The cell membrane maintains a transmembrane potential that is derived from the ION gradients, described by the NERNST EQUATION for the membrane potential. The key ions involved in the chemical potential are POTASSIUM (K^+), sodium (Na^+), and chlorine (Cl^-). In addition to the steady-state potential, the membrane can depolarize as well for an ACTION POTENTIAL that can communicate events to the central nervous system and the commands to the brain or to the muscles and the organs and glands. The DEPOLARIZATION process involves the active and passive transport of the key ions across the membrane by means of ion pumps and

opening and closing of selective pores: gates. One example is the ion selectivity of the KcsA Potassium channel. This ION CHANNEL has the ability to discriminate between K^+ and Na^+ ions, providing a mechanism for K^+ ions to pass through approximately 1000 times more rapidly than Na^+ ions. This channel has an equilibrium diameter of 40 Å, including the channel protein and a small portion of the membrane. The channel has an approximate length of 89 Å, including the length of the channel protein, as well as 30 Å intracellular space and 25 Å extracellular space. The channel protein provides what is known as the sodium–potassium pump as well as mitigating the passive ion conductivity. The potassium pump provides an active mechanism-of-action to restore the intra- and extracellular ion gradients. The electronic formation of the action potential is described by the HODGKIN–HUXLEY EQUATION. Transmembrane proteins that form the ion channels span the width of the lipid bilayer and support many cellular functions. Some of the transmembrane functions include proton transport (i.e., ACTIVE TRANSPORT: proton pump), water transport, but also act as receptors. A large portion of transmembrane sensors are chemical sensors in nature and belong to the seven transmembrane helix (7TM) family. Due to its chemical response, this receptor protein is popular in medication, and better than 50% of therapeutic and recreational drugs target members of this particular family. One specific receptor example is the transmembrane protein BACTERIORHODOPSIN. Bacteriorhodopsin has a segment that is light sensitive and responds with the onset of a process that can lead to an action potential within femtoseconds of being excited by a PHOTON. Note that a full transmembrane potential is required to reach a threshold of chemical imbalance (deviation from the steady state NERNST POTENTIAL) before the action potential sequence takes full effect. The bacteriorhodopsin harvests light energy and is present in the membranes of some halobacteria as well as in the RODS of the EYE. Bacteriorhodopsin converts the light energy to electrostatic energy, which in turn provides the vehicle to transport protons out of the cell (PTR). The resulting proton gradient (H^+) leads to a large pH gradient across the cell membrane. The acidity is then used to create renewable energy in ATP when the cell allows a proton to move back into the cell, by means of another transmembrane protein, ATP synthase. The PROTON transport is linked with the empirical valence bond (EVB), which defines the breaking and forming of associated chemical bonds, in particular the covalent bonding to hydrogen or dissociation of hydrogen. An important point about the EVB model is that the reaction must be carried out both in water and in the protein. For proton transfer (PT) reactions, the change in free energy of the PT can be obtained if one knows the reaction coefficient (pK_a values) of the donor (DH^+) and the protonated acceptor (AH). The Gibbs reaction energy is described as follows in

kcal/mol: $\Delta G_{PT}^w(DH^+ + A^- \rightarrow D + AH)_{\infty} = 1.38(\Delta pK_a^w)$, where ∞ represents the fact that the donor and acceptor are separated by a great DISTANCE (see Figure M.71).

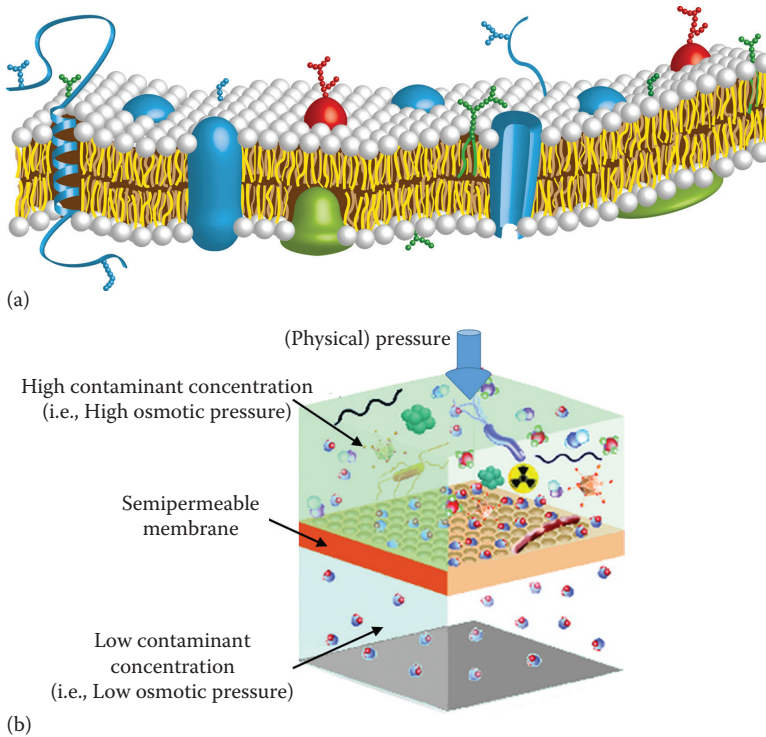


Figure M.71 (a) Illustration of the construction of the membrane of a biological cell and (b) the use of a membrane in water filtration by means of reverse osmosis.

Membrane capacitance

[biomedical, chemical, electronics] Considering a membrane equivalent electronic configuration composed of capacitance (C_m), RESISTANCE (R_i), and CURRENT (I) and voltage (V_{Nernst} , respectively, $\Delta\Phi_m$) sources, the equivalent circuit for a MEMBRANE can be represented by an electronic schematic. The storage of ionic charges on either side of the membrane presents similar concepts as a standard plate CAPACITOR does. This capacitor however is subject to ION leakage and mediated conduction, making the capacitance a time-dependent phenomenon. The cellular membrane ion pumps form the current sources, whereas the QUASI-STEADY-STATE single ion concentrations on the respective sides of the membrane generate a NERNST POTENTIAL (V_{Nernst}). The Nernst potential represents the chemical potential resulting from the ion concentration as well as the membrane ion DIFFUSION with respect to the individual ions: permeability. For additional ions, the membrane potential is described by the Goldman equation (introduced by DAVID E. GOLDMAN (1910–1998), ALAN LLOYD HODGKIN (1914–1998), and BERNARD KATZ (1911–2003); also known as the GOLDMAN–HODGKIN–KATZ VOLTAGE EQUATION): $V_{Goldman} = (RT/F) \ln \frac{p_{Na}[Na^+]_{out} + p_{K}[K^+]_{out} + p_{Cl}[Cl^-]_{in}}{p_{Na}[Na^+]_{in} + p_{K}[K^+]_{in} + p_{Cl}[Cl^-]_{out}}$. In this concept, the permeability constant for the ions of interest is represented by p_i^* , where the subscript signifies the ions: sodium (Na^+), POTASSIUM (K^+), and chlorine (Cl^-); square brackets denote the concentration of the respective ion ($[Ion]$); T is the temperature; R is the GAS constant ($R = 8.314 \text{ J/molK}$); and $F = 96485 \text{ C/mol}$ is the FARADAY CONSTANT. The subscripts “in” and “out” denote the ion migration for the CELL. A typical value for the RESTING POTENTIAL is -90 mV . It is negative because cells are more negative relative to the surrounding medium. Cells that are excitable have the ability to rapidly reverse the potential, causing it to be slightly positive. The potential that is generated in this process is known as the ACTION POTENTIAL.

The total sum of the currents can be described using KIRCHHOFF'S LAW (named after GUSTAV ROBERT KIRCHHOFF [1824–1887]): $C_m(d\Delta\Phi_m/dt) + I_{Na} + I_K + I_{Leak} - I_{pump} = 0$, where I_{Leak} represents the current resulting from free moving charges through orifices in the membrane, $\Delta\Phi_m$ is the Nernst potential across the membrane, I_{pump} is the current composed of ions forced into the cellular system, and I_{Na} and I_K respectively indicate the current from gated ion conduction for sodium and potassium. Including the respective ion conductance (g_i) and NERNST POTENTIAL for the ions involving the membrane capacitance is tied to the ion FLOW under steady-state conditions by OHM'S LAW as $C_m(d\Delta\Phi_m/dt) = I_{pump} - (\Delta\Phi_m - \Delta\Phi_{Na})g_{Na} - (\Delta\Phi_m - \Delta\Phi_K)g_K - (\Delta\Phi_m - \Delta\Phi_{Leak})g_{Leak}$. Also considered is the equivalent membrane circuit (see Figure M.72).

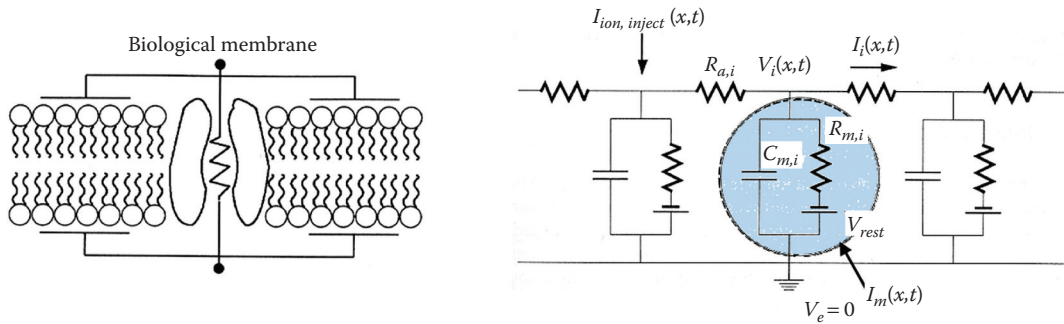


Figure M.72 Equivalent circuit for a biological cell, generally also capable of producing an action-potential.

Membrane potential

[biophysics, chemical, energy] Also called RESTING POTENTIAL of a CELL. Cells have the chemical and genetic content enclosed by membranes. The MEMBRANE controls the in and out flows of ions (e.g., nutrients and wastes) by means of voltage-gated gap junctions and ION channels. The trans-membrane potential is the result of ion composition difference between intracellular and extracellular compartments, next to the POLARIZATION of the molecules of the membrane in specific locations such as the ion channels. For every cell, two ionic solutions are separated by a membrane with similar and dissimilar ions on either side. The membrane is apparently permeable to some of the ions. This permeability results in both an electric potential and OSMOTIC PRESSURE across the membrane. This condition is known and the DONNAN EQUILIBRIUM between the two sides of the membrane. The CELL MEMBRANE is assumed to contain a one-for-one sodium/POTASSIUM ($Na^+ \leftrightarrow K^+$) exchange pump. However, the cell membrane is 50 times more permeable to K^+ and chlorine (Cl^-) than to Na^+ . The net efflux of 388 ions requires a net efflux of 69,840 H_2O molecules to maintain osmotic balance. In the intracellular compartment, potassium levels are high in comparison to the extracellular compartment. Sodium levels are high in the extracellular compartment in comparison to the intracellular compartment. In addition to the Na^+/K^+ -pump there will be free DIFFUSION, which is described by Fick's law: $J_s = -D(d[S]/dx)$, with D the diffusion coefficient and $[S]$ the arbitrary ion concentration and dx the DISTANCE over which the diffusion takes place. Additionally, there is a significant concentration of

negatively charged, impermeable proteins in the intracellular compartment that accounts for an appreciable portion of the **NEGATIVE CHARGE** in the intracellular compartment relative to the extracellular compartment. The separation of charges on either side of the cell membrane describes a **CAPACITOR** that has an electric potential associated with the charge distribution. A standard parallel plate capacitor consists of two conducting plates of area separated by distance d . A **POSITIVE CHARGE** (q^+) resides on one plate (i.e., extracellular liquid), while an effective negative charge (q^-) resides on the other (i.e., intracellular liquid). The electric field between the plates is $E = Q/A\epsilon_0 = \sigma_e/\epsilon_0$, where Q represents the total charge present on the plate with surface area A , yielding a surface charge density σ_e and ϵ_0 is the electric permittivity. This charge distribution provides an electric potential: $V = -d(Q/A\epsilon_0) = Q/C_m$, where d is the separation between the two plates and C_m represents the membrane capacitance. The initial description of the membrane potential used the ion distribution. **WALTHER HERMANN NERNST** (1864–1941) developed an equation simply describing membrane potential as being based on differing ion concentrations on the outside (extracellular: e) and inside (intracellular: i) of the membrane, which is described in equilibrium case (i.e., Donnan equilibrium,) as $V_m = V_i - V_e = (RT/nF) \ln([S]_e/[S]_i) = (KT/q) \ln([S]_e/[S]_i) = 26 \text{ mV} \ln([S]_e/[S]_i)$, where $F = 95,484.56 \text{ C/mol}$ is the Faraday's constant, that is, the charge on a **MOLE** of electrons multiplied by n the number of moles in the **SOLUTION**, q is the charge, $[S]_e$ is the extracellular ion concentration of one specific ion (" S "), $[S]_i$ is the intracellular ion concentration, $R = 8.314 \text{ J/mol}\cdot\text{K}$ is the **IDEAL GAS** constant, and K = the Boltzmann constant. This factors in that, in order for an ion to contribute to a membrane potential, the membrane must be permeable to that ion (*also see ACTION POTENTIAL*). The main ions involved in the transmembrane displacement current are **POTASSIUM** (K^+), **sodium** (Na^+), **chlorine** (Cl^-), and **calcium** (Ca^{2+}). In resting cells, the ion current from chlorine and calcium can be neglected. Each ion has a net current associated with the mobility (represented by the conductance) described as $I_S = g_S (V_m - V_S)$, where the subscript m designates the membrane potential and g_S is the ionic conductance for ion S . **DAVID E. GOLDMAN** (1910–1998) worked together with **SIR ALAN LLOYD HODGKIN** (1914–1998) and **SIR BERNARD KATZ** (1911–2003) to expand on the **NERNST EQUATION** including all **PERMEANT** ions describing the membrane potential as $V_m = (58 \text{ mV}) \log_{10} \left(\frac{p_{\text{K}}^* [\text{K}^+]_e + p_{\text{Na}}^* [\text{Na}^+]_e + p_{\text{Cl}}^* [\text{Cl}^-]_i}{p_{\text{K}}^* [\text{K}^+]_i + p_{\text{Na}}^* [\text{Na}^+]_i + p_{\text{Cl}}^* [\text{Cl}^-]_e} \right)$ (often referred to as the Goldman equation), where p_S^* is the **RELATIVE PERMEABILITY** for each specific ion. Some of the ion channels are responsive to external influences such as sound, **GRAVITY**, **OSMOTIC PRESSURE** gradients, and more, and these ion channels operate under a principle referred to as **MECHANOSENSITIVE ACTION** (see [Figure M.73](#)).

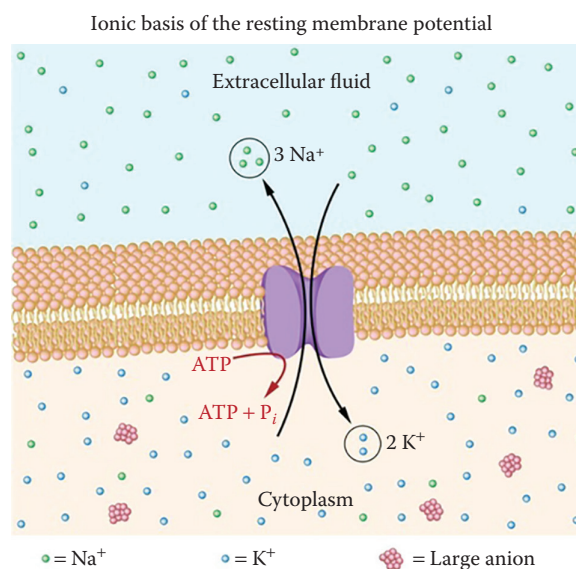


Figure M.73 Cell electrical potential mechanism based on chemical gradients.

Mendel, Gregor Johann (1822–1884)

[biomedical, computational, general] Scientist and friar in the then Austrian empire, now Czech Republic. Dr. Mendel realized the concept of chance in combination theory, in particular related to genetic transfer of recessive traits. He described in 1865 how the chance of the expression of the attributes of the recessive gene is related to the occurrence of the square root of the chance of the gene being carried forward (general concept of heredity). He is partially known as the father of modern genetic causality statistics. One of Mendel's professors in Vienna was CHRISTIAN ANDREAS DOPPLER (1803–1853) (see [Figure M.74](#)).



Figure M.74 Gregor Johann Mendel (1822–1884).

Mendeleev, Dmitri Ivanovich [Дми́трий Ива́нович Менделеев] (1834–1907)

[atomic, chemical, mechanics, nuclear, quantum, solid-state] Russian scientist and chemist. Mendeleev's discoveries of a pattern in the structural and energetic configuration of the ELEMENTS led to the composition of the PERIODIC TABLE OF ELEMENTS, based on the NUMERICAL patterns in atomic weights of known substances. He proposed the PERIODIC LAW, describing the electron configuration pattern for the ranking of elements. The QUANTUM THEORY was essential in explaining the perceived regularities. Mendeleev's work was pivotal in revealing the ATOM as the essential building block of the elements whether or not in molecular form. The periodic table is also referred to as Mendeleev's chart. The fact that the chart had several gaps led him to discover three additional elements: GALLIUM (1871), scandium (in 1879), and germanium (1886). Additional

work of Mendeleeev was in THERMODYNAMICS and GAS LAW. He described the concept of critical temperature before the experimental and theoretical verification in the 1860s by Thomas Andrews (1813–1885) (see [Figure M.75](#)).

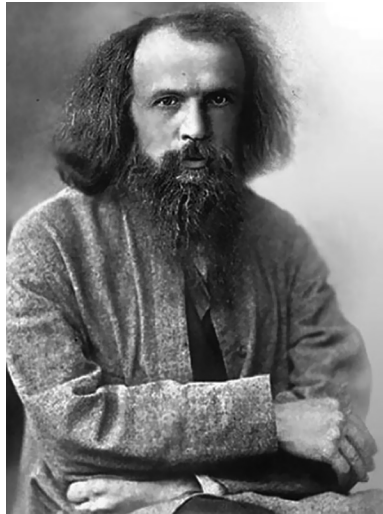


Figure M.75 Dmitri Ivanovich Mendeleeev (1834–1907).

Meniscus

[biomedical, mechanics] From the Greek word “μηνισκοζ” meaning crescent. Cartilage-based disk with the shape of a “C” positioned between the tibia and the femur acting as a SHOCK ABSORBER and reducer of FRICTION in the knee joint (see [Figure M.76](#)).

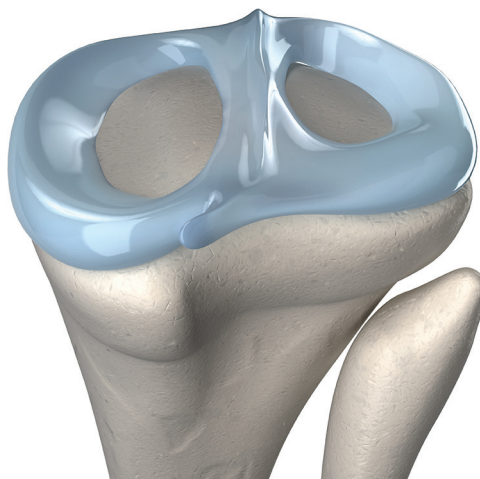


Figure M.76 Meniscus of the knee in the human leg.

Meniscus

[fluid dynamics, general] The curvature of a liquid surface in a confined space that holds the LIQUID to the surface by cohesive force, either concave (attractive force from the container, i.e., CAPILLARY [e.g., GLASS], is greater than the cohesive forces within the liquid) or convex (greater COHESION within the liquid) (see Figure M.77).

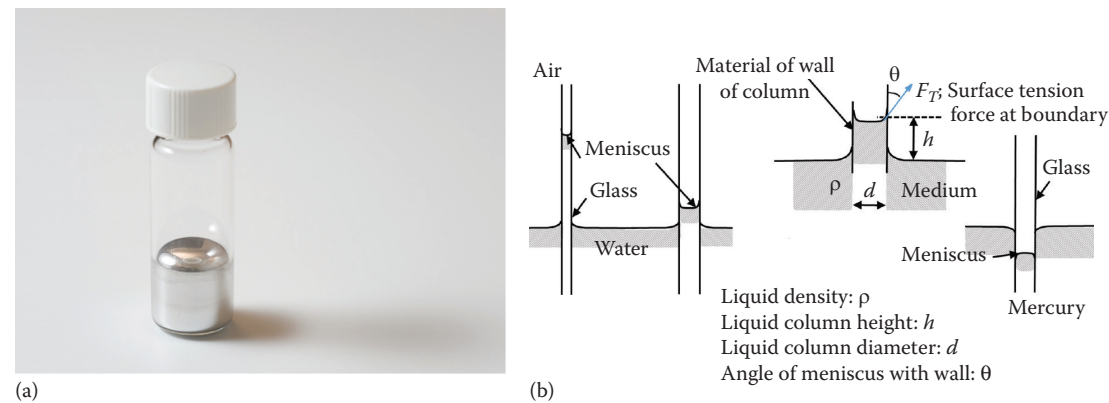


Figure M.77 (a,b) Liquid surface meniscus on mercury column in narrow flask.

Meniscus lenses

[biomedical, general, optics] Thin LENS used in spectacles (EYE glasses) for corrective VISION (see Figure M.78).

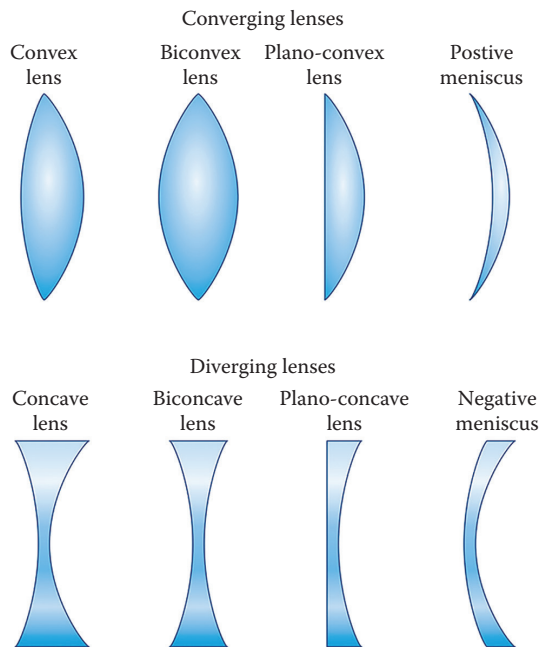


Figure M.78 Meniscus lens concept.

Menten, Maud Leonora (1879–1960)

[biomedical, computational] Canadian scientist, primarily known for her work related to MEDICINE, specifically on chemical reactions and enzyme KINEMATICS (*also see* LEONOR MICHAELIS (1875–1949) and MICHAELIS–MENTEN EQUATION) (see [Figure M.79](#)).



Figure M.79 Maud Leonora Menten (1879–1960). (Courtesy of Smithsonian Institution, Washington, DC.)

Menzel, Donald Howard (1901–1976)

[atomic, chemical, nuclear] Scientist from the United States. His work with RAYMOND THAYER BIRGE (1887–1980) led to the discovery of radio isotopes of hydrogen that occur under normal circumstance in a fraction of the whole with mass number 1 and 2 respectively in a 45,000:1 ratio, established in 1931. Additional contributions to the solid state and chemistry knowledge were in the description of the chemical structure of stars as well as the parameters of the physical structure of the CHROMOSPHERE of the Sun (see [Figure M.80](#)).

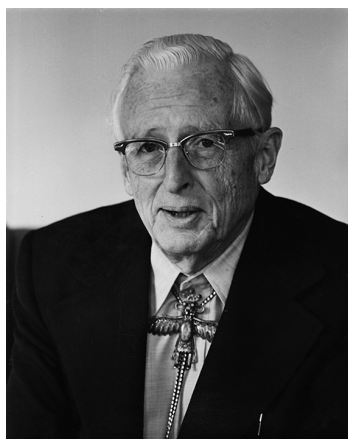


Figure M.80 Donald Howard Menzel (1901–1976), photograph by Babette Whipple. (Courtesy of Elizabeth Menzel Davis.)

Mercury barometer

[astrophysics, general, geophysics] Hollow device that has one LEG vacuum sealed, whereas the other leg is exposed to the outside AIR. The shape can be straight cylinder, U-shaped, or tube in a basin exposed to outside air with the top sealed. Through the law of COMMUNICATING VESSELS, the column of mercury rises and lowers when the force on the exposed mercury MENISCUS varies with the external pressure; hence, the height in the VACUUM column is an indication of the force applied by the outside air, with height (h) reaching to the edge of the ATMOSPHERE and density ρ , on the surface area in equivalence to the force applied by the height of the column of mercury. Hence the PRESSURE (P) is sometimes expressed in height (h) of millimeters mercury from $P = \rho gh$. The first MERCURY BAROMETER was introduced by EVANGELISTA TORRICELLI (1608–1647) in 1643. The term mercury barometer is attributed to ROBERT BOYLE (1627–1691) (see [Figure M.81](#)).

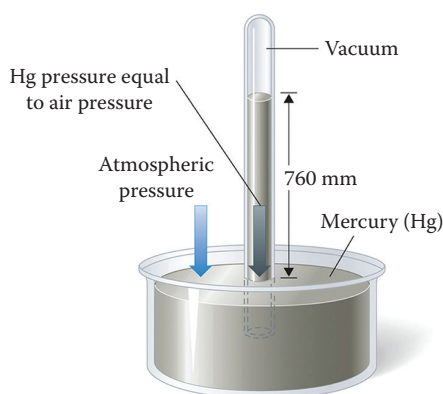


Figure M.81 Diagram of open mercury barometer. (Courtesy of Bruce A. Averill and Patricia Eldredge.)

Mercury cell

[general] Solid-state disposable BATTERY with “dry-cell” potential of 1.4V. The advantage of the mercury cell battery is the small size (as used for instance in calculators, HEARING aids, and watches).

Mersenne, “father” Marin (1588–1648)

[acoustics, computational, general] Scientist, theologian, mathematician, and experimentalist from France. Marin Mersenne is often referred to as the father of ACOUSTICS. Father Mersenne was a contemporary of Constantijn Huygens (1596–1687), composer and poet, and the father of the physicist CHRISTIAAN HUYGENS (1629–1695) from the Netherlands, and GALILEO GALILEI (1564–1642), with both he exchanged scientific communications, as well as with numerous other international collaborators of that era. His specific interests were in restructuring the European mathematics efforts and worked with Étienne Pascal (1588–1651), as well as his son BLAISE PASCAL (1623–1662) among other people. Due to his fascination with music, he also became well versed in the acoustics phenomena and described the technical details in 1627, including the dependence of the FREQUENCY (ν) on a string as a function of the square root of the applied tension (F_T) and with respect to the length (ℓ) and mass (m), yielding the resonant frequencies of a string with linear mass density $\mu_\ell = m/\ell$.

(specifically accounting for the diameter of the string), providing base frequency ($n = 1$) and higher harmonics ($n = 1, 2, 3, \dots$): $v_n = n/2\ell\sqrt{(F_T/\mu_\ell)}$. His work also provided an in-depth definition and range of values for the speed of SOUND (see [Figure M.82](#)).



Figure M.82 “Father” Marin Mersenne (1588–1648).

Merton mean speed theorem

[computational, general] Lemma proposed by a group of academics from Oxford, United Kingdom (the so-called Oxford Calculators of Merton College), and French collaborators in the fourteenth century (including the mathematician NICOLE ORESME [c. 1320–1382]), stating that a body that is unvaryingly accelerated will travel an equal DISTANCE as a body with uniform speed, when the accelerated body has a speed that is half its final velocity. The theorem attempts to quantify uniformly accelerated MOTION by matching it to uniform motion.

Meson

[energy, general, nuclear, quantum] Elementary particle component of one quark and one antiquark. A short-lived particle carrying a positive, negative, or zero charge, and having a variable mass in multiples of the mass of the electron. Also called mesotron. They are the complementary particles of BARYON, another subclass of the PARTICLE group HADRON. Mesons, which obey BOSE–EINSTEIN STATISTICS and have zero or integral SPIN ($s = 0, 1, 2, \dots$), are also known as bosons. The known mesons are π , K , ρ , ω , η ; K (heavy), K_A ON, L (light), μ (μ) and π (π), and π ION; and most recently a four-quark hadron: $Z(4430)$ has been introduced, consisting of two quarks and two antiquarks. In contrast, baryons obey FERMI–DIRAC STATISTICS and have half-integral spin; they are also known as fermions. Masses of the known mesons as well as baryons range from one-seventh of that of the PROTON for the π meson, extending 10 times the proton mass. Mesons are subjected to the STRONG NUCLEAR FORCE, in contrast to the LEPTON (see [Figure M.83](#)).

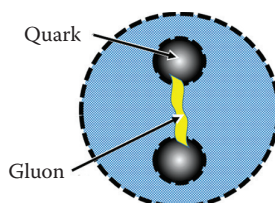


Figure M.83 Graphical representation of the Meson concept.

Meson theory of nuclear forces

[atomic, nuclear] Hypothesis basing the assumption of a nucleon–nucleon potential, a MESON field, which has similarities with electromagnetic fields however with a much greater force and much shorter range. Also known as the Yukawa theory.

Mesosphere

[energy, geophysics] Atmospheric layer between the stratopause and the mesopause, at an altitude between approximately 50 and 80 km. A type of LIGHTNING referred to as sprites can appear in the mesosphere above thunderstorms. In this layer, near the North and South POLES peculiarly, high-altitude noctilucent clouds are sometimes formed (see [Figure M.84](#)).

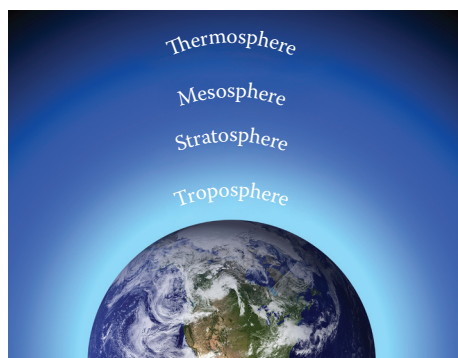


Figure M.84 Mesosphere of earth's atmosphere.

M

Metabolic activity

[biomedical, chemical, thermodynamics] The full complement of all chemical reactions that supports and maintains the cellular ACTIVITY (i.e., “life”) in an organism. Metabolic activity involves the transformation of MATTER to ENERGY on a cellular level. Both ELEMENTS are required to sustain life. Two types of metabolic processes are available on a chemical level: anabolic and catabolic. The anabolic METABOLISM is constructive, forming large molecules from small molecules in an ENDOTHERMIC PROCESS. The catabolic mechanism is exothermic and breaks down large molecules. Every person has an individualized metabolic rate, depending on hormonal balances and past and present activity, with inherent AGE and gender related implications. Due to this individualized metabolic activity, a purely nutrition-based weight control by means of diets never yields the same outcome for everyone. A baseline metabolic rate can be used linking CALORIC consumption requirements against the weight of the biological entity.

Metabolic flux analysis (MFA)

[biomedical, chemical, computational] Methodology for the determination of the migration of metabolic chemical pathway fluxes. The intracellular fluxes are derived from a model for the major intracellular reactions based on intracellular MASS BALANCE for all respective metabolites. The stoichiometric model defines the metabolic flux-pathway map, representing the CONSERVATION OF MASS on a purely chemical level, that is, atomic constituents. The parameters used in the computational process are the physical quantities of extracellular fluxes, as measured by chemical concentrations, including the derived representative uptake rates of substrates as well as secretion rates of metabolites. The FLUX calculations provide a multiparameter diagram of the biochemical reactions with an approximation of the steady-state rate for each individual reaction in the diagram (i.e., the flux); this yields a metabolic flux map. MFA studies are executed by making cells consume a radioactively labeled substrate (e.g., ^{13}C -labeled GLUCOSE). Subsequently the incorporation of the ISOTOPE is measured to determine the reaction mechanism. The downstream metabolites are derived from mass spectrometry. The computational model of the intracellular metabolic network defines the pathway fluxes

in association with physical measurements of extracellular nutrient consumption and constituent excretion rates of the respective isotope- labeled data. The detection mechanism relies on the production of microbes with imbedded ^{13}C -labeled glucose, followed by gas-CHROMATOGRAPHY mass spectrometric QUANTIFICATION of amino acids with protein-bound ^{13}C -patterns. By systematically accounting for all extracellular ^{13}C in and out fluxes as well as all other major intracellular pathways, the MFA can simulate and recreate the cellular METABOLISM based on comprehensive flux maps. The metabolic flux analysis network describes the conversion of fundamental raw material S_0 into substance S (consider for instance the intake of substrate from outside of the cell). Subsequently, substance S is converted into material A and B through the respective reactions r_1 and r_2 . Furthermore, A is converted to chemical substance C by reaction r_3 , and reaction r_4 converts constituent B into D . In general, the reaction in the map does not contain the specific stoichiometric information. The map is supplied with additional biochemical reactions, for which the stoichiometric relationships have been established and verified. The following examples are an indication of potential sequence of events: glucose + PEP $\rightarrow$ glucose - 6 - P + pyruvate, where PEP represents phosphoenolpyruvic ACID, which can be converted to glucose; respectively: pyruvate + NADH $\rightarrow$ lactate + NAD^+ , or glucose - 6 - P + ATP $\rightarrow$ 2 - glyceraldehyde - 3 - P + ADP, where ATP (ADENOSINE TRIPHOSPHATE) and ADP (ADENOSINE DIPHOSPHATE) are the energized and reduced forms of the renewable intercellular ENERGY source and NADH (nicotinamide adenine dinucleotide) the coenzyme and electron donor. The potential reaction balance proceeds as follows: reaction 0 (raw material conversion): $S_0 \xrightarrow{r_0} S$; respectively $S \xrightarrow{r_1} A$, $S \xrightarrow{r_2} B$, $A \xrightarrow{r_3} C$, and $B \xrightarrow{r_4} D$. In these cases, the material balance turns out to be: $dS_0/dt = -r_0$; $(dS/dt) = r_0 - r_1 - r_2$; $dA/dt = r_1 - r_3$, $dB/dt = r_2 - r_4$; $dC/dt = r_3$; $dD/dt = r_4$, where r_i is the respective reaction rate for each process, which can be represented in matrix format, yielding the stoichiometric matrix $\tilde{G}$, and the reactions are captured by the reaction vector

$$\tilde{v} = \begin{pmatrix} r_0 \\ r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix},$$

providing

$$\begin{pmatrix} S_0 \\ S \\ A \\ B \\ C \\ D \end{pmatrix} = \tilde{G}^T \tilde{v} = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} r_0 \\ r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix},$$

where

$$\begin{pmatrix} S_0 \\ S \\ A \\ B \\ C \\ D \end{pmatrix}$$

represents the state vector, containing the state variables (see Figure M.85).

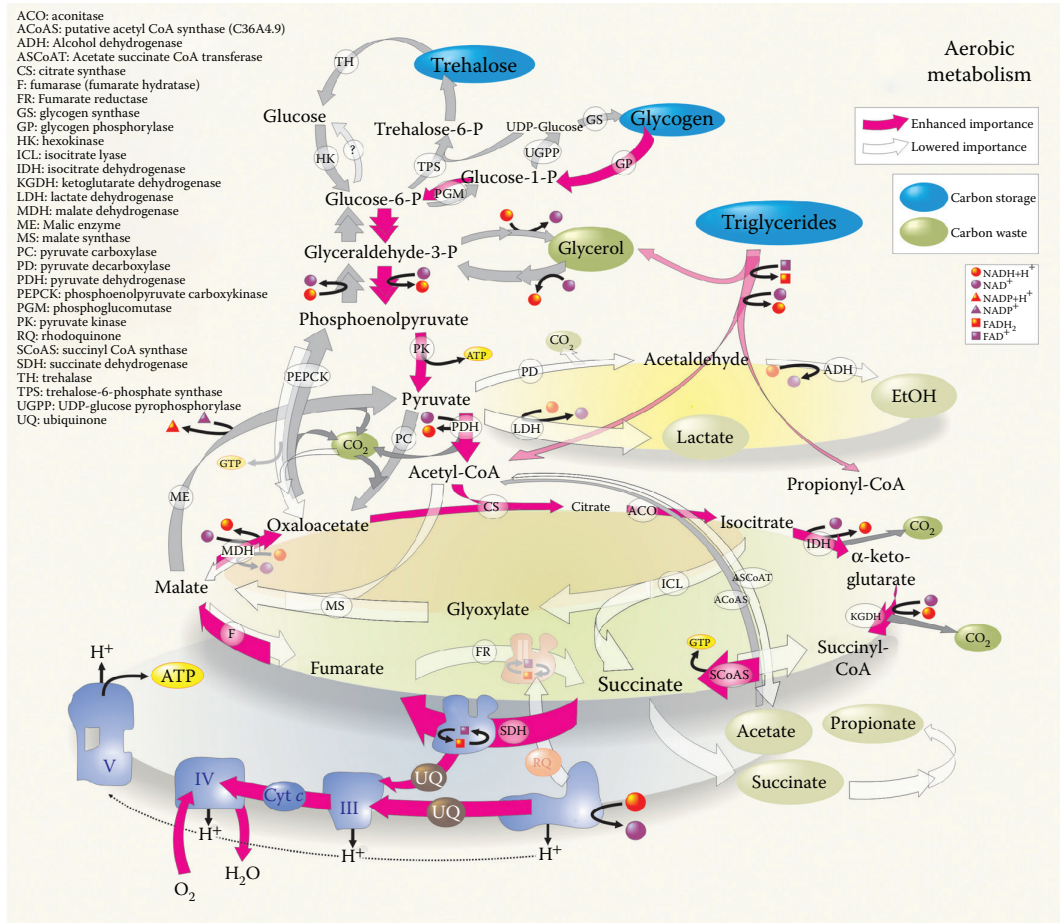


Figure M.85 Metabolic activity schematics. (Courtesy of Intermediary metabolism; Bart P. Braeckman, Koen Houthoofd, Jacques R. Vanfleteren. Wormbook; Intermediary metabolism (February 16, 2009), WormBook, ed. The C. elegans Research Community, WormBook, doi/10.1895/wormbook.1.146.1, http://www.wormbook.org/http://www.wormbook.org/chapters/www_intermetabolism/intermetabolism.pdf.)

Metabolism

[biomedical, chemical, computational] Cellular physiological process of chemical conversion (e.g., consumption; for instance, proteins and carbohydrates) and formation of the renewable ENERGY source ADENOSINE TRIPHOSPHATE (ATP) from ADENOSINE DIPHOSPHATE (ADP) and phosphor under influence of nucleic ACID catalysts and enzymes such as insulin. The process is dependent on the formation of solutes from solids (with a specific rate constant) and relies on DIFFUSION for some of the supply passive mechanisms as well as ACTIVE TRANSPORT through the cellular MEMBRANE. The metabolic pathway also involves the RESPIRATION process for oxygen supply used for OXIDATION and exothermic reactions. The metabolic process can be modeled in a first-order approximation by an EULER METHOD, linking the respective chemical constituent gradient in the chemical PHASE TRANSITION (f) by location (x_n , with neighbor x_{n+1}) as $x_{n+1} = x_n + \Delta x f(x_n, y_n)$, and in second order by the RUNGE-KUTTA approximation $k_1 = x f(x_n, y_n)$, where k_1 is the formation rate of phosphorylation of enzyme R by kinase, with R representing the concentration of enzyme R, x a location parameter;

$k_2 = \mathcal{N}f(x_n + (1/2)x, y_n + (1/2)k_1)$, where k_2 is the loss rate of phosphorylation of enzyme R by a pH change influence, and $x_{n+1} = x_n + k_2 + \mathcal{O}(x^3)$, with $\mathcal{O}$ a chemical reaction function (with an associated reaction response).

Metacenter

[fluid dynamics] The theoretical vertical line passing through the center of BUOYANCY with respect to the vertical line passing through the CENTER OF GRAVITY when a floating body is tipped, hence crating a torque. The center of buoyancy is the effective center of the displaced fluid (e.g., the FLUID displaced by the hull of a ship), the point where the buoyant force is theoretically acting on under steady-state conditions (see Figure M.86).

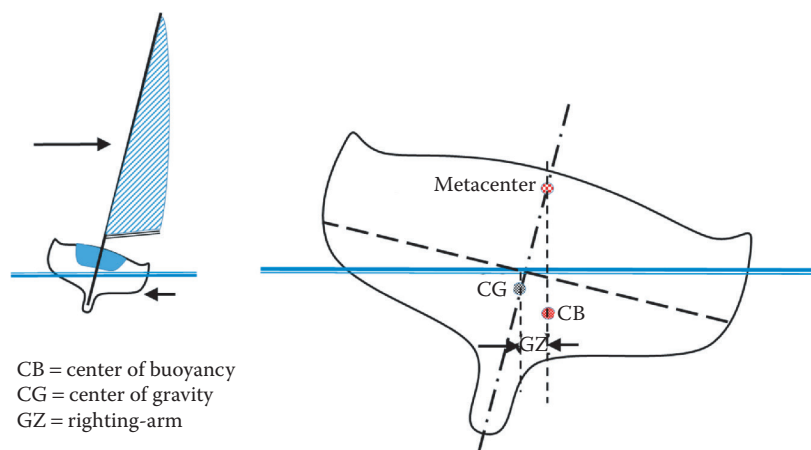


Figure M.86 Metacenter, in this case outlined for a tipping sail-boat.

Metacentric height (h_m)

[fluid dynamics] Condition for the stability of a solid floating body. A specific example is found for ships, in particular with respect to a solid load. The DISTANCE between the center of mass of the floating body and the METACENTER for the floating body (h_m), where the CENTER OF GRAVITY should exert a torque with respect to the metacenter that forces the floating object to erect itself, meaning prevent it from tipping over. Metacentric height has consequences for the natural period of rolling for the hull of a ship. A large metacentric height will result in shorter periods of roll, which will create uncomfortable sensations generally for passengers. Specifically there is an optimal range associated with the metacentric height for stability and comfort. The period of roll (T_{roll}) is expressed as $T_{\text{roll}} = 2\pi R_g / \sqrt{gb_m}$, where g is the GRAVITATIONAL ACCELERATION, and $R_g = \sqrt{I/A}$ the RADIUS OF GYRATION, also referred to as gyradius, where I is the MOMENT OF INERTIA of the object in the direction of roll, and A is the surface area of the buoyant object under the LIQUID surface. The radius of gyration is a measure of the size of an object, in this case the surface of a floating body, given by the root mean square distance for a representative number of locations on the surface of the objects and associated parts with respect to the center of gravity over the length of the object. This will place a limitation on the validity of the radius of gyration with respect to a minimum longitudinal dimension.

Metal

[general, mechanics, nuclear, quantum] ELEMENT or alloy with a shine, the metallic shine and have a high density. Metals are generally not pliable. Metals are conductive for electric current and are good thermal conductors at room temperature; however, not all metals are magnetic. Certain metals are LIQUID at room temperature, for instance mercury and gallium-based alloys, since GALLIUM is generally not found in free form. The conductivity of metals is the result of one or more loosely bound valence

electrons that can easily be freed. The relative ease of releasing the outer electron results from a low IONIZATION ENERGY and low ELECTRONEGATIVITY for the respective ELEMENTS. Metals are found in the PERIODIC TABLE OF ELEMENTS as groups; group IA and group IIA (the alkali metals, which can be considered the most active metals) and the transition elements, groups IB to VIIIB. Alkali metals have their outermost (VALENCE) electron in an s-electron configuration (the BOHR ATOMIC MODEL) orbit. Metals include, but not limited to, the following elements: aluminum, caesium (cesium), calcium, copper, francium, gallium, germanium, gold, IRON, lead, LITHIUM, mercury, neodymium, platinum, potassium, rubidium, silicon, silver, sodium, TITANIUM, uranium, and additionally alloys such as brass and bronze. Most metal oxides are transparent (most well-known metal oxides: the ceramic [white] aluminum oxide $[Al_2O_3]$, and the transparent silicon oxide $[SiO_2]$), specifically also forming garnet crystals. The metallic structure relies on the metallic bonds holding the atoms together. Metallic bonds are electromagnetic interactions between atoms resulting from delocalized electrons (the conduction electrons), basically allowing the valence electrons to share hosts. The quantum-mechanical aspect of the metallic bound allows the conduction electrons to distribute their density (as a “cloud”) equally over all atoms, where the atoms inherently function as neutral (noncharged) entities. The metallic structure relies on close-packed fitting, with as many atoms as possible into the available atomic volume. Each ATOM in this structure has 12 touching neighbors. For the applicable metals, this is described as “12-co-ordinated.” Certain metals are packed less densely (notably those in group 1 of the periodic table), having only 8 neighboring atoms touching. These configurations are called “8-co-ordinated.” Generally metals are not dramatically efficient in their organization. Any piece of metal is made up of regions of regularity, consisting of grain boundaries at which the atoms have become misaligned from the ideal homogeneous LATTICE structure, forming “crystal grain.” The “crystal grains” allow for the formation of localized current loops, creating localized magnetic fields as described by the BIOT–SAVART LAW. These current loops, and implied associated MAGNETIC FIELD vector, can line up to form a PERMANENT MAGNET.

M

Metal detector

[electronics, general] Detection device responding to the changes in DIELECTRIC properties, which result in a change in the self-inductance of a coil in an *LRC* circuit (INDUCTOR (*L*), RESISTOR (*R*), and CAPACITOR (*C*) electronic resonator), with the inherent change in resonant frequency $\omega_0 = (LC)^{-1/2}$ ($\nu = \omega_0/2\pi$), with the bandwidth defined by the QUALITY FACTOR: $Q = \omega_0 L/R$. The bandwidth provides a means of separation with respect to particular electronic material properties. This mechanism of action is applied to passengers on airport screening, and by treasure hunters looking for coins and jewelry (see [Figure M.87](#)).



Figure M.87 Metal detector, popular tool for treasure hunters.

Metal fatigue

[general, mechanics] Localized gradual structural damage to a structure made from alloys or metals resulting from cyclic or infrequent repetitive loading in addition to thermal stress, either gradients or broad range fluctuations (with associated EXPANSION/contraction patterns in three-dimensional configuration). The FATIGUE results from applied nominal maximum stress below the ultimate TENSILE STRESS of the material, and generally less than the yield stress limit. When a certain stress threshold is exceeded, on a MICROSCOPIC level, certain threshold, cracks will form, weakening the integrity of the structure on a MACROSCOPIC scale. The continued exposure to the forces involving the implementation of MATERIAL FATIGUE will eventually result in breakage. Forces can for instance result from geophysical origins such as wind generating a RESONANCE of earthquakes, or man-made such as traffic, and repetitive use. One specific example is the TACOMA NARROWS BRIDGE disaster (November 7, 1940) resulting from a specific wind FLOW causing the suspension cable to provide a resonance VIBRATION (aeroelastic flutter) that made the bridge collapse after an exposure over a 2-year time frame, ultimately resulting in a severe oscillatory MOTION that lasted only a few hours when exposed to a steady 65 km/h wind from the southwestern direction (perpendicular to the axis of the bridge), generating a mixed WAVE pattern consisting of transversal, longitudinal, and rotational vibration modes (see Figure M.88).



Figure M.88 Broken key that has bent beyond the failure-mode, or bent multiple times, causing thermal restructuring of the internal molecular build-up to loose cohesion.

Metastable state (equilibrium)

[atomic, nuclear, thermodynamics] An excited state of a NUCLEUS or an ATOM with a short lifetime, which returns to the GROUND STATE by the emission of a GAMMA RAY or visible or infra-red electromagnetic emission over a measurable half-life. The excited state of an atom that, in QUANTUM mechanical terms, describes the transition from “forbidden” metastable states, which are less probable than the ALLOWED TRANSITIONS from other vetted EXCITED STATES. Particularly, the lifetime of an excited state that is *longer* than the ordinary excited states and that is universally shorter than the lifetime of the ground state, which is the lowest energy state, and is predominantly stable. Nuclides with identical numbers of protons but different neutrons are referred to as isotopes, in metastable state. The nuclides with measurable (“long-lived”) life-time have isomeric energy states that are identified as separate nuclei, respectively, designated as ISOMERS. On a MACROSCOPIC level, this also applies to the nonpreferential, and hence less stable, physical condition of a system that can be long-lived with respect to the system’s most stable state. The latter has as example isomerization. In isomerization high-energy isomers are perpetuated by the creation of (conceivably large) BARRIERS in the potential energy, preventing degrading to the ground state. Atomic metastable conditions can be identified by for instance the ZEEMAN EFFECT, based on spectroscopic diagnostic principles. Another macroscopic example on LATTICE base for carbon at standard temperature and pressure is diamond as a metastable form. Diamond can degenerate to graphite, providing excess kinetic energy, only after overcoming the POTENTIAL BARRIER associated with the crystalline LATTICE structure, captured by dispensation of activation energy. The computational aspects of metastability can for instance describe the energies and lifetimes of ionic and molecular states, including but not limited to vibronic and rotational–vibronic states. On macroscopic scale, the metastable

state can refer to a condition that may release potential energy as kinetic energy, such as an avalanche for a metastable mass of snow on the edge of a mountain cliff (*also see LASER*) (see [Figure M.89](#)).

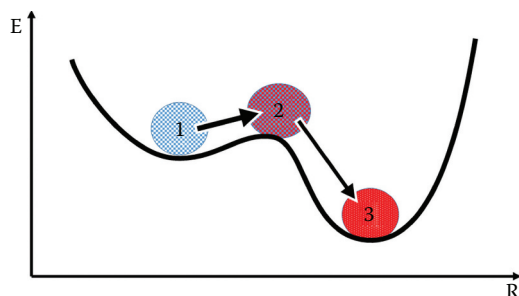


Figure M.89 Energy configuration for a metastable state: a metastable state of weaker energy configuration [potentially an atomic bond, or vibrational state, or cohesive attraction on macroscopic scale] (#1), a transitional ‘saddle’ configuration (#2) and a final state of stronger bond (#3).

Meteor

[astrophysics, geophysics, mechanics] Encounters of galactic projectiles with the Earth’s ATMOSPHERE, were the burn up, and create a visible flash. The observed flash is referred to as a meteor. Meteors occur in the thermosphere. Meteors enter the Earth’s ATMOSPHERE at velocities generally ranging from 10 km/s to 75 km/s, keeping in mind that the earth’s angular velocity in an orbit around the Sun is on average 30 km/s. Also known as “shooting star,” a visible streak of light across the field of view. One of the annually reoccurring meteor showers is the Perseid meteor shower in the first part of August, associated with the COMET Swift Tuttle. The Perseid meteor shower received its name from the direction at which it is seen entering the Earth’s ATMOSPHERE, with the constellation Perseus in the background. This particular meteor shower has been dated back to 36 AD in Chinese astronomical records, but the annual recurrence was documented by Adolphe Quetelet (1796–1874) from Belgium in 1835 (see [Figure M.90](#)).



Figure M.90 Meteor entering the Earth’s atmosphere.

Meteorite

[astrophysics, geophysics, mechanics] Solid space debris released by the break-up of comets and ASTEROIDS.

Meteoroid

[astrophysics, geophysics, mechanics] The smallest projectiles within the SOLAR SYSTEM, ranging in size from large fragments released by the breakdown of ASTEROIDS or comets, to dust expressed as extremely small micrometeoroids.

Meteorology

[energy, fluid dynamics, general, geophysics] Field of PHYSICS dealing with physical phenomena in the lower part of EARTH'S ATMOSPHERE directly related to the weather and providing warnings for people in the path of inclement weather. Several devices have been developed in relation to this field such as the ANEMOMETER, BAROMETER, HYGROMETER, RAIN GAUGE, THERMOMETER, and wind vane (see [Figure M.91](#)).



Figure M.91 Aspect of meteorology. Illustrations of the duties and roles in meteorology.

Meter (m)

[general] Dimension of length in the Systèm International (SI) units system. The origins of the meter date back to the early part of the eighteenth century. The meter was defined as the length of a PENDULUM having a half-period of 1 s; later this was superseded under the rule of Napoleon Bonaparte (1769–1821) in 1791 as 10^{-7} time the length of the meridian through Paris from the pole to the equator. However, there is an inherent error in this definition due to the flattening of the EARTH due to its rotation, introducing a deviation of 0.2 mm. In 1889 the meter was defined as the DISTANCE between two marks on a bar of alloy of platinum with 10% iridium, “accurate” within 0.0001%. In 1960 the definition was replaced by the wavelength of the emission from krypton-86 (transition between $2p_{10}$ and $5d_5$, generating a wavelength of 605.7 nm), specifically $1/299,792,458$ (reference speed of light) of the distance traveled in a VACUUM over 1 s interval (placing the accuracy within the definition of measurement of time).

Method of moments

[acoustics, computational, fluid dynamics, mechanics] One of the oldest NUMERICAL (i.e., discrete) computational methods for obtaining point estimators, primarily based on the LAW OF LARGE NUMBERS. The SOLUTION mechanism is based on solving linear partial differential equations that have been reformulated as integral equations. In an arbitrary experiment, there will be an observable, real-valued variable X based on PROBABILITY. The distribution of the variable X can be assigned with n unknown parameters. The set of parameters can be represented by a virtual n -dimensional parameter space, with the vector coordinate $\bar{\chi} = (\chi_1, \chi_2, \chi_3, \dots, \chi_k)$. In order to fully define the vector, the system needs to be measured k -times, which yields a mean $\langle \chi \rangle = 1/k \sum_{i=1}^k \chi_i$ and VARIANCE (σ^2) . The method of moments estimator for the variance provides $\Sigma^2 = \Sigma_2 - \langle \chi \rangle^2 = 1/k \sum_{i=1}^k (\chi_i - \langle \chi \rangle)^2$. This mechanism essentially solves for boundary

conditions, rather than for the analog stretch of continuous space of the media and objects. In the process of formulating the interaction of electric and magnetic fields with MATTER and the environment, the method of moments provides a tool to solve the MAXWELL EQUATIONS. The method of moments can for instance be used to calculate ANTENNA configuration, efficacy, and function, as well as compatibility with the environmental and atmospheric conditions for interaction with ELECTROMAGNETIC RADIATION, specifically the electromagnetic WAVE propagation in a medium other than in free space (i.e., VACUUM). The key component in the solution mechanism is the formulation of Maxwell's equations as a system of hyperbolic partial differential equations. Alternatively, the objects and the media themselves can be approximated as a distribution of discrete dipoles in order to approximate SCATTERING and absorption of electromagnetic radiation by targets of arbitrary geometry. The accuracy will depend on the number of defined interactions (nuclei in the media, and objects) in the system. Also referred to as the method of weighted RESIDUALS.

Metric system

[general] Units scaled in decimal proportions (yotta: 10²⁴ ...→ yocto: 10⁻²⁴) (see SI-UNITS, Le SYSTÈME INTERNATIONAL D'UNITÉS).

VALUE	VALUE: NORMAL	NOUN	PREFIX (SI)	SYMBOL
1.0E+24	1 000 000 000 000 000 000 000 000	Septillion	Yotta-	Y
1.0E+21	1 000 000 000 000 000 000 000 000	Sextillion	Zetta-	Z
1.0E+18	1 000 000 000 000 000 000 000	Quintillion	Exa-	E
1.0E+15	1 000 000 000 000 000 000	Quadrillion	Peta-	P
1.0E+12	1 000 000 000 000 000	Trillion	Tera-	T
1.0E+9	1 000 000 000	Billion	Giga-	G
1.0E+6	1 000 000	Million	Mega-	M
1.0E+3	1 000	Thousand	Kilo-	k
1.0E+2	100	Hundred	Hecto-	h
1.0E+1	10	Ten	Deca-	da
1	1	—		
1.0E-1	0.1	Tenth	Deci-	d
1.0E-2	0.01	Hundredth	Centi-	c
1.0E-3	0.001	Thousandth	Milli-	m
1.0E-6	0.000 001	Millionth	Micro-	μ
1.0E-9	0.000 000 001	Billionth	Nano-	n
1.0E-12	0.000 000 000 001	Trillionth	Pico-	p
1.0E-15	0.000 000 000 000 001	Quadrillionth	Femto-	f
1.0E-18	0.000 000 000 000 000 001	Quintillionth	Atto-	a
1.0E-21	0.000 000 000 000 000 000 001	Sextillionth	Zepto-	z
1.0E-24	0.000 000 000 000 000 000 000 001	Septillionth	Yocto-	y

Metrology

[acoustics, fluid dynamics, general, mechanics, optics] The science of all practical and theoretical aspects of taking and recording measurements.

Michaelis, Leonor (1875–1949)

[biomedical, computational] Physician from the Prussian Empire, Germany, biochemist, and physical chemist. Michaelis worked with MAUD MENTEN (1879–1960) on the mathematical description of enzymatic kinetic interaction and reaction equations (*also see* MICHAELIS–MENTEN EQUATION) (see [Figure M.92](#)).



Figure M.92 Leonor Michaelis (1875–1949). (Courtesy of Humboldt-Universität zu Berlin, Berlin, Germany, Universitätsbibliothek.) Porträtsammlung Berliner Hochschulelehrer; Historische Sammlungen der Universitäts-Bibliothek; Berlin, Germany.

Michaelis–Menten equation

[biomedical, computational] Mathematical description of the transport of substrates (concentration: $[S]$) and drug-related events that have an enzyme (concentration: $[E]_0$) as a catalyst to drive the reaction. Mediated DIFFUSION is faster than regular diffusion described by the DIFFUSION EQUATION. The reaction will have a production rate (v_{reaction}) that changes with time and is dependent on the chemical concentrations of the constituents. An example of this type of reaction is the binding of oxygen to hemoglobin, which for one depends on the partial oxygen pressure next to the acidity (pH) among other factors such as a catalyst. Frequently the SOLUTION is derived by graphical interpretation with for instance the EADIE–HOFSTEE PLOT. The need for this type of computational approach is due to the often ill-defined experimental boundary conditions. The Michaelis–Menten equation is best described as $v_{\text{reaction}} = V_{\text{max}}([S]/(K_M + [S])) = k_{\text{cat}}[E]_0([S]/(K_M + [S]))$, where V_{max} is the maximum reaction velocity, K_M is the Michaelis–Menten constant, indicating the concentration at which the reaction rate for the enzyme is at half the maximum production rate or reaction velocity, and k_{cat} is the rate of conversion for the substrate molecules to the final product, also referred to as the turnover number. In this case, a small Michaelis–Menten constant (K_M) indicates a high binding affinity. Other applications are for instance DNA–DNA hybridization, and antigen to antibody binding (*also see* LANGMUIR EQUATION for equivalence in the description of ADSORPTION of biomolecular constituents, next to nuclear reactions).

Michelson, Albert Abraham (1852–1931)

[acoustics, atomic, biomedical, general, optics] Physicist and scientist from Germany/Poland, born in what was at the time known as the Kingdom of Prussia, later immigrated to the United States. Michelson is primarily known for his contributions in OPTICS. In 1907 Albert Michelson received the Nobel prize in Physics for his work in SPECTROSCOPY and optical instrumentation (see [Figure M.93](#)).



Figure M.93 Albert Abraham Michelson (1852–1931). (Courtesy of Smithsonian Institution.)

Michelson interferometer

[acoustics, atomic, biomedical, general, optics] Path length balanced device that generates INTERFERENCE when the path of the ENERGY traveling to and from the target or probe site is equal to the length of the path traveled by the identical energy signature (frequency, PHASE, designation [PARTICLE, electromagnetic, pressure wave, etc.] and other parameters of identification and material conditions) in a standardized reference path. The path length equivalence is determined by the coherence length of the WAVE package. The Michelson interferometer can be free space or fiber optic. The Michelson interferometer is characterized by four arms, one incoming, one arm that leads to the target (probe site), one reference arm, and the fourth provides the mechanism of detection of interference as a sensor branch. An optical balancing construction where a beam is split into two components that are branching off in perpendicular directions to interact with two media in the respective arms of the INTERFEROMETER, mainly reflective objects returning the two beams back to a 4th arm where they reunite and the wave patterns interact based on the respective phases of the two beams of electromagnetic

radiation as a function of location. When the light is in phase, the interference will be constructive, alternatively when in the opposite phase the waves will cancel each other (destructive interference) (see Figure M.94).

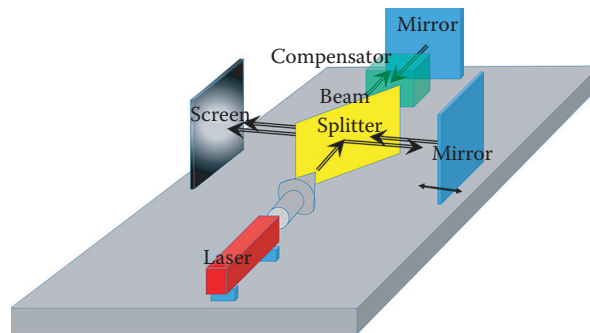


Figure M.94 Michelson interferometer.

Michelson–Morley experiment

[atomic, nuclear] Experimental design to prove/disprove the existence of ether (also known as AETHER), by ALBERT MICHELSON (1852–1931) and EDWARD MORLEY (1838–1923) in 1887. Ether is the historically assumed medium for the propagation of ELECTROMAGNETIC RADIATION, a concept dating back to BC from the philosophies of the Greek scientists. The experimental sign was attempting to determine the relative MOTION of the EARTH with respect to the perceived LUMINIFEROUS ETHER. The design of the experiment used an INTERFEROMETER to determine the path length difference traveled between arms of a split beam of light. In case the path length of two arms (each with length L_{arm}) is equal, the light will be additive (constructive interference). A similarity can be found with swimming a track parallel to the FLOW of a river and perpendicular respectively, returning at the point of origin over equal distances, executed by two equally capable swimmers departing exactly at same time. The difference in path length expressed as the time traveled along the “ether” and perpendicular to the ether was expressed as $\Delta t \cong (L_{\text{arm}}/c)\beta_M^2$, where $\beta_M = v/c$, with v the speed of the object, and $c = 2.99792458 \times 10^8$ m/s the speed of light. The movement of the Earth would account for the lengthening/shorting of the measuring arm, while the reference arm would remain constant, resulting in a shift of INTERFERENCE fringe in the sensing arm. This phenomenon however went unobserved and the ETHER concept was dismissed. The MICHELSON INTERFEROMETER will provide a respective fringe shift for influence of moving ether expressed as $n = \ell v^2 / \lambda c^2$, where ℓ is the respective arm length, and λ the wavelength of the light.

Microarray

[biomedical] A lab-on-a-chip. A two-dimensional array constructed on a solid substrate, made of a GLASS or silicon thin-film CELL. The array assays a large quantity of biological material. The miniaturized microarray detection method is primarily used in DNA analysis, and through high-throughput

screening, multiplexed and PARALLEL PROCESSING of the configuration of the complex molecule can be derived (see [Figure M.95](#)).

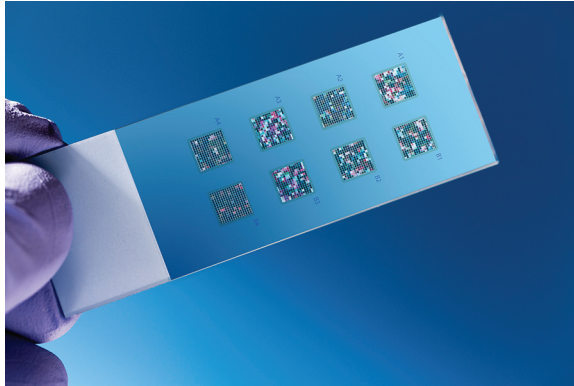


Figure M.95 DNA-Microarray.

Microelectronic-mechanical systems (MEMS)

[acoustics, electronics] Electromechanical systems of integrated electronic and mechanical interactions of components (see [Figure M.96](#)).



Figure M.96 MEMS device miniature microphone/speaker set.

Microfluidics

[biomedical] Fluid manipulation in conduits with dimensions of less than 1 mm diameter. Microfluidics is found in biological PERFUSION, inkjet printers, and “lab-on-chip” designs for chemical analysis as well as targeted delivery at a MICROSCOPIC level. The RHEOLOGY of blood in capillaries is an example of microfluidics that changes the FLUID behavior due to the size of the red blood cell, forming a flat velocity profile in the center of the tub.

Microgravity

[biomedical, general] Projectiles in free fall are generally considered to be weightless. Microgravity can be created in a plane flying in a parabolic arc lasting only several seconds (see [Figure M.97](#)).

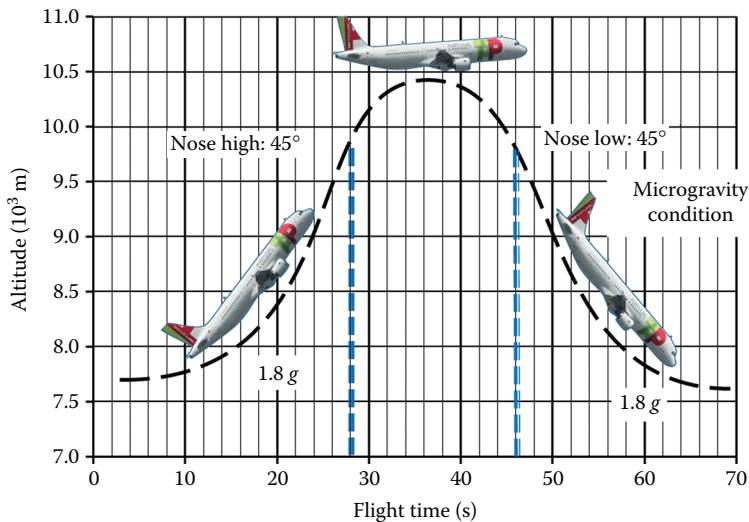


Figure M.97 The time event for microgravity during specialized flight patterns.

Microphone

[acoustics, electronics] Device designed to convert pressure fluctuations into an electronic SIGNAL from recording purposes or for real-time amplification and transmission over loud speakers or over RADIO or television channels as well as telephone systems (including mobile phone and ham-radio). A microphone can be constructed from piezoelectric material that under mechanical deformation produces an electric signal that changes in frequency and AMPLITUDE in direct correlation (cause-and-effect) with respect to the

external mechanical stimulus. The mechanical stimulus can be changed in density of a GAS, or physical compression due to movement of a mass of solid or LIQUID (see [Figure M.98](#)).



Figure M.98 Microphone, classic design.

Microprocessor

[electronics, general] Integrated circuit used for performing computational algorithms. Semiconductor CHIP containing a central processing unit (CPU) electronic circuit configuration. The first microprocessor was introduced in 1974 by the Intel® Corporation (founded in 1968) with 8-bit capability, leading to the rapid reduction in the size of the computer to a portable device. The microprocessor forms the HEART of every modern day computer and control unit. Microprocessors provide the logic for most digital devices, ranging from fuel injection to nuclear power plant temperature regulation. The microprocessor is designed with a specific clock speed, well in excess of 2.4 GHz at the time of this work, indicating the number of calculations that can be performed per SECOND. Next to the processor speed, a microprocessor is classified by the bandwidth of the SIGNAL; 8-, 16-, 32-, 64-, or 128-bit (not common in personal computers [PCs]). The processor's "bit" parameter refers to the MAGNITUDE of the data types that the processor can handle next to the size of its registry. A 64-bit processor has the capability of

storing 264 computational values, where the data are also temporarily stored in memory addresses. The 64-bit CPU is hence capable of accessing over 10^9 times as much physical memory in comparison to a 32-bit processor (see [Figure M.99](#)).

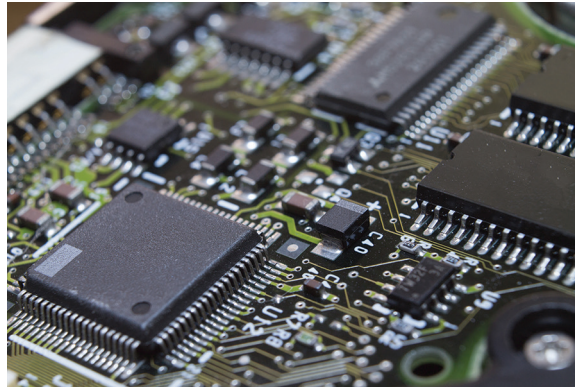


Figure M.99 Microprocessor.

Microsaccade

[biomedical, electronics, theoretical] μ -saccade, small random movements (plural) of the EYE across the field of view outlined by the azimuthal and the polar ANGLE in a spherical coordinate system. The movement is predominantly involuntary and is supposedly designed (biologically) to avoid retinal SATURATION. Ocular fixation on a single point in the view will eventually bleach out and will become invisible unless the eye moves away from this point. The body is generally more responsive to change than to status quo. This small amount of eye movement is disorganized with no preferential pattern. Other MOTION of the eye with respect to fixation on a view-point is classified as TREMOR and DRIFT. The movement is shorter than a regular SACCADIC. The angular motion in humans and animals ranges from 2 to 120 arcmin. This phenomenon was first documented by Robert Darwin (1766–1848) a medical doctor from Great Britain, the father of the naturalist, genetic researcher, and geologist Charles Darwin (1809–1882). Microsaccades also provide the mechanism for the visual interpretation that a pattern of small markings in a dense distribution is moving when looking at it in a fixed stare (see [Figure M.100](#)).

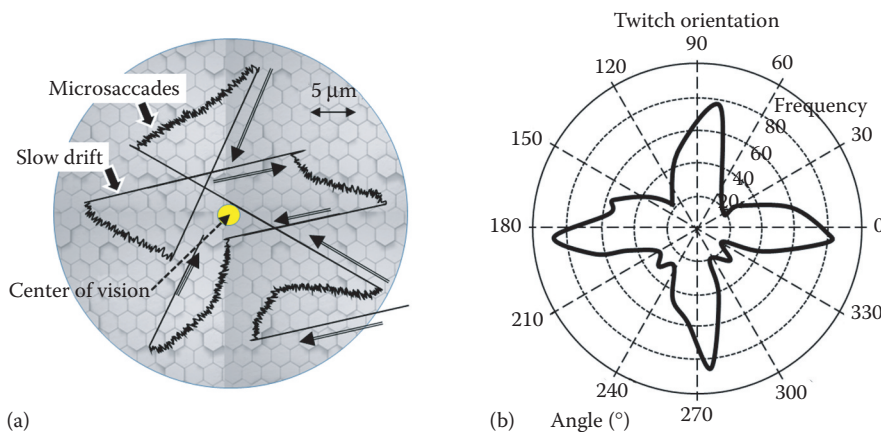


Figure M.100 (a) Illustration of how the microsaccades, high-frequency twitches, are superimposed on the normal drift motion (saccades) of the eye movement and (b) representative frequency and angular distribution of microsaccades.

Microscope

[general, imaging, optics] Device used to provide a detailed view of an object with greater RESOLUTION than what can be obtained with the naked eye, with no specific lower limit on the magnification. The standard microscope was what we now consider a magnifying GLASS. The MICROSCOPE is generally constructed of one or more optical ELEMENTS, including lenses, mirrors, and prisms. The use of more than one optical ELEMENT constitutes the compound microscope. The standard optical microscope was developed between 1590 and 1608, independently (debatably), by two teams of LENS makers (eye glasses) from the Netherlands: HANS JANSEN (sixteenth century, no exact dates), and ZACHARIAS JANSEN (1580–1640) and HANS LIPPERSHEY (1570–1619). The microscope was the result of experimentation with lenses since the first eye-glasses were introduced between 1282 and 1285 in Florence, Italy by Alessandro di Spina. The concept was the culmination of the publication of the properties of curved glass providing magnifying by ROGER BACON (1214–1294) in 1262. The compound microscope is attributed to ROBERT HOOKE (1635–1703) in Great Britain, created in 1665, while a similar device was concurrently constructed by Jan Swammerdam (1637–1680) in the Netherlands in 1675. The Hooke microscope was actually constructed by a London instrument maker named Christopher Cock (seventeenth century, no exact dates). The Hooke microscope attained a magnification of 30 times. The Swammerdam microscope reached magnification of 150 times. The microscope was improved by the lens-maker ANTONIE VAN LEEUWENHOEK (1632–1723) from the Netherlands, published in 1716. The van Leeuwenhoek microscope used pinholes and lenses made from water droplets. This device was used in the eighteenth century for the equivalent to current medical pathological investigation. Microscopes in the early 1700s were made using crown glass. In 1733, a breakthrough discovery was made by the amateur optician, Chester Moor Hall (1703–1771) from Great Britain, minimizing CHROMATIC ABERRATION through a combination of lenses made with different refractive materials to form a complex lens. This discovery can be attributed to the introduction of a new lead-containing flint glass. The microscope forms an IMAGE of an object placed in the (adjustable) FOCAL PLANE of a set of or single magnifying glass(es). The magnifying glass is a biconvex axial symmetric glass spheroid. Light reflects from the object (specimen) placed under the lenses and is refracted at the air–glass interface and again exiting at the glass–air interface. In case the formed image cannot be projected on a screen, it is defined as a virtual image. Alternatively when the image can be projected on a screen, the image is defined as real. The refracted light is hence focused by the lens providing the formation of an image, either virtual or real. When a virtual image is formed, the EYE can observe this on the RETINA, appearing on the same side of the lens, and in the approximately similar azimuth and ZENITH locations, as where the object is located. The virtual image formed by the lens and observed by the eye is most sharp when its position falls in the NEAR POINT of the eye. The near point of the eye is the closest DISTANCE between an object and the cornea of the lens of the eye that can be perceived as a well-defined image by the retina. The near point for the average human being is approximately 250 mm removed from the cornea. In order to understand the function of the microscope, first some of the basic principles of ray forming by a single lens in image formation need to be described. Two general types of lenses can be distinguished: concave and convex. A concave lens is thinner on the optical axis than farther removed from the axis of symmetry. Concave lenses are also called diverging lenses since they will never produce a real image. Convex lenses are thicker on the optical axis and will produce a real image on the opposite side of the lens when the object is at a distance greater than the focal length. When the object is at a distance shorter than the focal length, the convex lens will also form a virtual image. The distance on the optical axis of the lens with respect to the material center to the plane where the light from an object at infinity forms the smallest real image, generally undistinguishable since all rays from every point on the object converge, is known as the focal distance f . The focal length is positive for the convex lens (also known as POSITIVE LENS) and the focal length for a concave lens is negative (virtual, and this lens is also called a “negative lens”). The image of the object formed by the convex lens appears inverted in the FOCAL POINT. The power of the lens is defined as the inverse of the focal length of the lens. The image formed by any lens is a factor or fraction greater than the object. The object has a height b_o , the image has a height b_i , and the distance of the image to the lens is d_i , while the object distance from the lens is d_o . The lateral magnification for a simple lens is defined as the ratio of the image height over the object height, which can be shown by geometric analysis to be equal to the ratio of the respective distances as $M = b_i / b_o = d_i / d_o$. Modern microscopes have a minimum of two lenses or two lens sets (corrections for chromatic and spherical

aberration), and objective and an ocular. The ocular lens is located in the eyepiece of the microscope. The ocular generally has a magnification of 10 times. The objective lens is placed closest to the specimen on the examination stage. The objective is selected to suit the required total magnification for the investigation of details with the appropriate resolution. The total magnification is the product of the two respective magnifications for the two lens systems. Based on the Raleigh criterion or **ABBE CONDITION**, the maximum magnification for a standard optical microscope operating at the wavelength with peak retinal sensitivity (570 nm) is 600 times. Different types of microscope have been developed to overcome the limitations in **OPTICAL MAGNIFICATION**. Additionally, the standard optical microscope has been outfitted with techniques to take advantage of the electromagnetic parameters, including phase and wavelength, and polarization **ANGLE** to enhance the contrast for optimization in detection of deviations from the norm. One type of microscope takes advantage of the wave properties of light and is called the **INTERFERENCE** microscope, taking advantage of the fact that the optical path length varies with local index of **REFRACTION**. The **PHASE** contrast microscopy also relies on interference of light waves, with deviations resulting from diffraction, with associated phase retardation. Another type of microscope uses the **DISPERSION** of light in tissues based on the direction of the electric field and the direction of the electric influences of the medium under investigation, known as **BIREFRINGENCE** of most tissues. In particular, the loss of the birefringence resulting from clinical (disease) or external damage to the tissue, artificially induced (e.g., coagulation), and is referred to as polarization microscope. Many other **MICROSCOPIC** devices have been developed over time, not all based on the optical principles. Some optical microscope variations are fluorescent microscopy, confocal microscopy, scanning optical microscopy, two-photon microscopy, and near-field-scanning optical microscopy. One of the latest microscope introductions is three-dimensional imaging with optical coherent tomography (**OCT**) imaging devices, based on the phase information of the wave property of light, relying on interference. Microscopes using other techniques are the **ELECTRON MICROSCOPE** based on the **DE BROGLIE WAVELENGTH** of an accelerated charge **PROJECTILE** as does the helium-ion microscope. Additional resources are the **ATOMIC-FORCE MICROSCOPE (AFM)** using the electronic attraction and repulsion of the medium and an extremely fine needle tip mounted on a cantilever (see [Figure M.101](#)).



Figure M.101 Microscope.

Microscope, atomic force

[general] See **ATOMIC FORCE MICROSCOPE**.

Microscope, compound

[general] See **MICROSCOPE** or see **COMPOUND MICROSCOPE**.

Microscope, confocal

[general] See **CONFOCAL MICROSCOPE**.

Microscope, electron

[general] *See* ELECTRON MICROSCOPE.

Microscope, He-ion

[general] *See* HELIUM-ION MICROSCOPE.

Microscope, nuclear

[general, nuclear] *See* NUCLEAR MICROSCOPE.

Microscope, resolving power

[atomic, nuclear] *See* RESOLVING POWER.

Microscope, scanning ion-conductance

[general] *See* SCANNING ION-CONDUCTANCE MICROSCOPE.

Microscopic

[biomedical, chemical, general, solid-state] Not visible by the naked eye, requiring visual aids to identify the characteristics; that is, the use of a magnifying GLASS or MICROSCOPE.

Microstate

[general, mechanics, thermodynamics] Thermodynamic condition that applies to a MICROSCOPIC subsegment of a system. This principle applies specifically to statistical MECHANICS. The assembly of all local microstates dictates the collective macrostate of the medium or entire system.

Microtome

[biomedical, mechanics] Precision cutting device used for preparation of histology slides. The tissue in most cases is embedded in paraffin after being fixed first in formaldehyde or equivalent chemical. Additional operational mechanism of action employs a frozen section and the device is called a cryostat microtome (see [Figure M.102](#)).

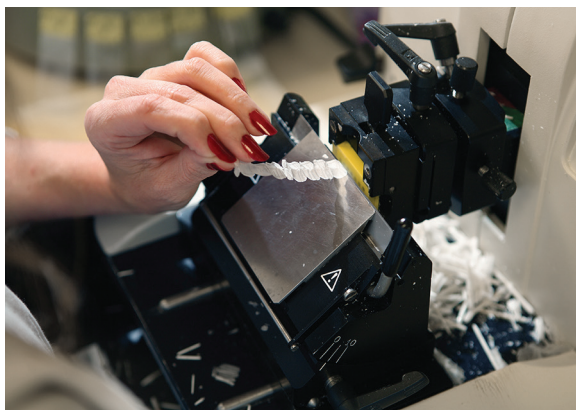


Figure M.102 Microtome cutting device used for histology slide preparation. An extremely thin slice of tissue imbedded in paraffin is cut from the large formaldehyde fixed block and curls off the blade. The wafer-thin slice of tissue is subsequently placed on a microscope glass-slide for examination of the tissue structure and potential identification of pathological deviation in cell structure (e.g., cancer cells mixed-in with the regular organ cells) under microscopic examination.

Microwave

[general] Electromagnetic WAVE in the wavelength spectrum ranging from order of millimeter to 1 m, or equivalently, with frequencies ranging from 300 to 0.3 GHz. Most well-known is microwave radiation in the 2.54 GHz range (wavelength: $\lambda = 124$ mm), used in wireless communications such as CELL phones and bluetooth, and the heating of food in the MICROWAVE OVEN. Microwave radiation is generally produced by a magnetron electronic device (see [Figure M.103](#)).

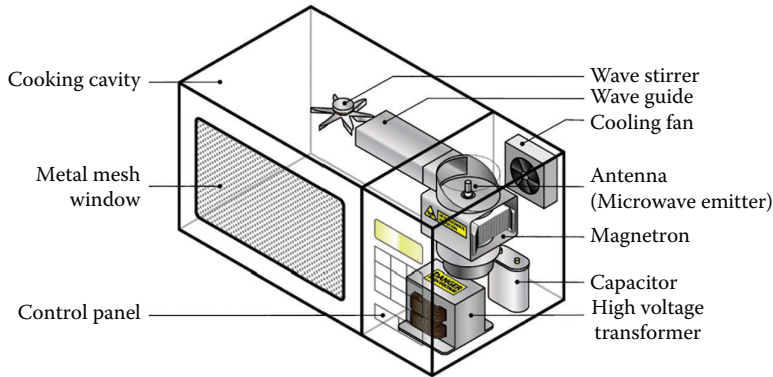


Figure M.103 Microwave with magnetron signal generator depicted.

Microwave imaging

[general] Due to the relatively high-penetration potential of microwave radiation through various media as a function of wavelength, the use of microwave ELECTROMAGNETIC RADIATION can be used as a mechanism for functional and anatomical imaging of biological media as well as for commercial imaging, such as radar. On a biological scale, the electromagnetic interaction with DEPOLARIZATION of groups of cells forms a perturbation that can be localized using line-of-sight, specifically when applying multiple rays at a relative ANGLE with each other in a synchronous detection mechanism arranged in circular symmetry. Radar (acronym for radio detection and ranging) relies on the deflection and detection for boundaries under an operating mechanism very similar to ultrasonic biological imaging and ultrasonic radar. The use of frequency modulation provides an added mechanism for enhanced RESOLUTION and spectral information about the physical properties of the object under scrutiny (see [Figure M.104](#)).

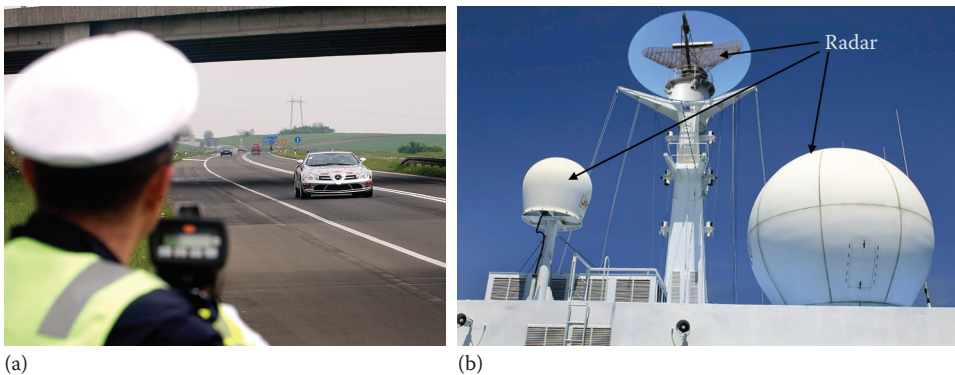


Figure M.104 (a) Microwave signal detection used by police officer for the assessment of the velocity of moving automobiles and (b) spinning RADAR antenna on a ship for reconnaissance.

Microwave oven

[general] Device that relies on the use of millimeter ELECTROMAGNETIC RADIATION for vibrational excitation of MOLECULAR MOTION (i.e., DIELECTRIC heating), resulting in localized heating of the object. The local temperature is the average kinetic ENERGY of the molecular vibrations ($T = (3/2k_b)mv^2$, where k_b is the Boltzmann coefficient, m is the average molecular mass, and v is the vibrational, rotational, and translational velocity). The use of primarily 2.54 GHz limits the use to heating of materials that contain water such as meat or just liquids. The frequency of 2.54 GHz still has relatively low absorption in water vibration, which ensures deep penetration and volumetric heating. High attenuation at higher frequency MICROWAVE will result in primarily surface heating. Large industrial ovens operate at 0.915 GHz (see [Figure M.105](#)).



Figure M.105 Microwave oven used to heat-up a cup of tea.

M

Middle ear

[biomedical, general] Anatomical segment in the HEARING mechanism for mammals conveying the longitudinal pressure WAVE incident on the eardrum (tympanic membrane) at the end of the OUTER EAR, to the oval window on the cochlea of the INNER EAR. The middle ear has a mechanism of controlling the LOUDNESS of the sound propagated to the inner ear (primarily to prevent structural damage as well as increase the AMPLITUDE and frequency resolution). The pivoted bone system (OSSICLES) in the middle ear consisting of the malleus (“hammer”), incus (“anvil”), and stapes (“stirrup”) that can be relaxed with respect to its interconnection, hence reducing the MAGNITUDE of translational movement; reducing the AMPLITUDE applied to the oval window. Keeping in mind that the tympanic MEMBRANE is 20 times larger in area than the oval window, this indicates the first mechanism of “amplification” available for hearing. The ossicles can respond to a

displacement of the tympanic membrane in the order of nanometers, setting the lower limit of hearing at (approximately) 0 dB at approximately 3500 Hz for a healthy young human ear. With excessive loudness, the fibrous/muscular connections between the ossicles wear down, reducing the sensitivity, leading to gradual procession of deafness. Additionally age-related degeneration of the ELASTICITY of biological materials hearing will decline in both frequency response and intensity sensitivity (see [Figure M.106](#)).

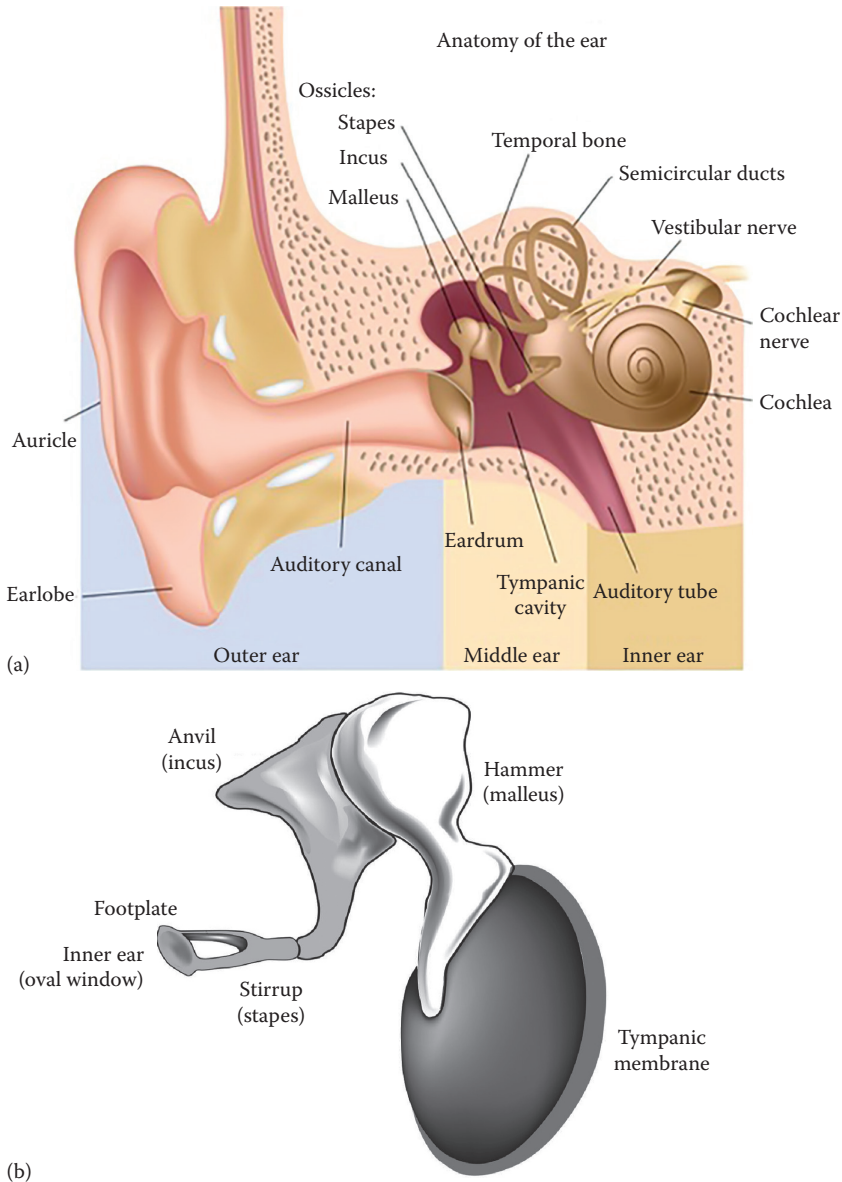


Figure M.106 (a) Full diagram of auditory subsystem (ear) and (b) outline of the Middle ear for *Homo sapiens* (humans); left to right: eardrum, malleus, incus, stapes. The eardrum forms the separation from the outer-ear, whereas the stapes are connected to the inner ear at the oval window.

Mie, Gustav Adolf Feodor Wilhelm Ludwig (1868–1957)

[optics] Physicist from Germany. Mie is best known for his description of the interaction of light with large particles in 1908. MIE SCATTERING stand in comparison to RAYLEIGH SCATTERING for PARTICLE size equal to or smaller than the wavelength (see Figure M.107).



Figure M.107 Gustav Adolf Feodor Wilhelm Ludwig Mie (1868–1957).

Mie absorption

[astrophysics, biomedical, optics] Numerical method used to calculate the maximum absorption coefficient of a medium constructed primarily of spherical particles in clear (i.e., transparent) suspension. In line with the spherical geometry of the particulate constituents, the model is symmetric that allows for SEPARATION OF VARIABLES in the HELMHOLTZ EQUATION $(\nabla^2 + k^2)\Psi(r, \theta, \phi) = 0$, in spherical coordinates, where ∇ is the Laplace operator, and $k = \omega/c = 2\pi/\lambda_0$ the WAVENUMBER, where $\omega = 2\pi\nu$ is the ANGULAR VELOCITY, ν the frequency, λ_0 the wavelength of a monochromatic electromagnetic source, and c the speed of light) for the interaction of the RADIANT ENERGY FLUENCE RATE (Ψ) with the medium that applies to this condition. Separation of variables ($\Psi(r, \theta, \phi) = R(r)\Theta(\theta)\Phi(\phi)$), with a radial component $R(r)$, a cylindrical component $\Theta(\theta)$, and an azimuthal component $\Phi(\phi)$, results in three ORDINARY DIFFERENTIAL EQUATIONS $(d^2\{rR(r)\}/dr^2 + (k^2 - [n(n+1)]/r^2)rR(r) = 0$, where n is a separation constant with solutions as spherical BESSEL FUNCTIONS or spherical Hankel functions of the first kind or spherical Neumann functions, $(1/\sin\theta)(d/d\theta)(\sin\theta(d\Theta(\theta)/d\theta)) + (n(n+1) - m^2/(\sin\theta)^2)\Theta(\theta) = 0$, where m is another separation constant with a LEGENDRE FUNCTION ($P_n^m(\theta)$) as solution $\Theta(\theta) = P_n^m(\theta)$, and $d^2\Phi(\phi)/d\phi^2 + m^2\Phi(\phi) = 0$ with $\Phi(\phi) = e^{im(\phi)}$. From these solutions, the absorption efficiency for a sphere (Q_{abs}) can be derived, which is a direct representation of the ABSORPTION COEFFICIENT (μ_a): $Q_{\text{abs}} = 2/\xi \sum_{n=1}^{\infty} \{(2n+1)[\Re(a_n + b_n) - (|a_n|^2 + |b_n|^2)]\}$, where a_n and b_n are coefficients that are functions of the size parameters: $\chi = kr_i$ and $\xi = k(r_i + e)$.

Mie scattering

[astrophysics, computational, optics, particle] Theoretical approximation of the attenuation resulting from SCATTERING based on a spherical particle model. Mie scatter stands next to RAYLEIGH SCATTERING for atomic and molecular media, such as the creation of the blue sky by means of atmospheric gasses. Both the directional pattern (profile of scattering ANGLE) and magnitude of attenuation resulting from redirecting the electromagnetic WAVE while interacting with DIELECTRIC units with spherical geometry in transparent suspension

(e.g., tissue model, space dust, atmospheric vapor [i.e., haze/fog/clouds] or dust, and paint). In the case where the dimension of the PARTICLE characteristics of the ELECTROMAGNETIC RADIATION interacts (i.e., WAVICLE) with is of the order of MAGNITUDE of the WAVELENGTH of the RADIATION, the interaction closely approximates GEOMETRICAL OPTICS. A more precise definition involves the SOLUTION of the MAXWELL EQUATIONS applied to the interface with an isotropic, homogeneous, dielectric sphere. The Maxwell equations solved in spherical coordinates yields the SCATTERING CROSS SECTION: σ_M , and a SCATTERING ANISOTROPY FACTOR: g (see [Figure M.108](#)).



Figure M.108 Overcast sky, potentially with dust, providing Mie scattering red glow.

The scattering anisotropy factor is also described by what is generally referred to as a SCATTERING PHASE FUNCTION. The scattering phase function is defined by the PROBABILITY of a PHOTON being scattered in the direction θ , expressed by $P(\theta)$. This yields $g = \int_0^{4\pi} P(\theta) \cos\theta \, d\omega$, where ω represents the SOLID ANGLE of space. This can also be expressed in vector format. In this case photons are approximated as rays. A photon is regarded as coming in from direction $\vec{s}$, and after scattering the photon path is redirected into direction $\vec{s}'$. This provides the following statement for the angular scattering probability distribution: $g = \int_0^{4\pi} P(\vec{s}, \vec{s}') \cdot (\vec{s}, \vec{s}') \, d\omega$. This accounts for events taking place over the full 4π steradian, a.k.a. spherical geometry. This process often assumes spherical symmetry, which accounts for a radially, and often axially, homogeneous medium.

Milky Way

[astrophysics, thermodynamics] GALAXY constructed of stars, planets, and dust and GAS in which the Earth's SOLAR SYSTEM is located. The generally accepted view and calculated description of the Milky Way is a flat dual "cymbal" shaped assembly of over 100 billion stars and in the order of 400 billion planets. A rough estimate of the diameter of the Milky Way is at this moment in the order of 5.22×10^4 lightyears. The "bulge" in the center of the Milky Way has a spheroidal distribution of stars and planets and potentially a "BLACK HOLE" in the center. The currently accepted value of the DISTANCE of the Sun from the galactic center is 2.77×10^3 light-years, or 8.5 kiloparsecs (a parsec is equal to 2.06×10^5 times the average distance between the Sun and the EARTH), located approximately half-way between the center and the edge of the Milky Way galaxy. A resembling shape of a spiral galaxy is shown for the Splinter Galaxy. All planets, gasses, and stars revolve around the center of the Milky Way in a uniform fashion, with relatively a constant rotational velocity in the plane of the disk; the velocity at the location of our SOLAR SYSTEM is

approximately 240 km/s. The disk of the Milky Way is surrounded by a spheroidal collective of stars, described as a halo, which is seemingly devoid of gasses and dust (see [Figure M.109](#)).



Figure M.109 Reconstruction of what the Milky Way may look like observed from within the distant galaxy (so far we have not traveled outside our solar system), let alone outside our Milky Way.

M

Miller indices

[atomic, nuclear] “Vector” style notation system in crystallography to specify directions and planes in crystal lattices (namely Bravais lattices). The Miller index for a plane defines how the plane intersects with any of the main crystallographic axes of the crystal, respectively solid, and also applies to any parallel plane (*also see* LATTICE PLANES) (see [Figure M.110](#)).

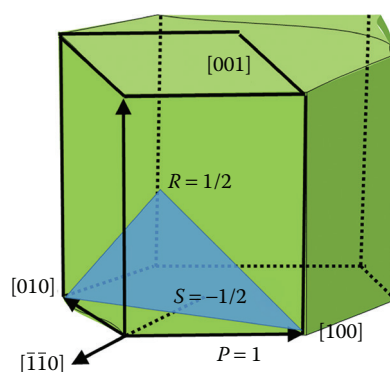


Figure M.110 Miller indices for atomic lattice structures.

Millikan, Robert Andrews (1868–1953)

[atomic, general, nuclear] American scientist and experimentalist. Millikan's contributions to the nuclear model are in his "oil-drop" experiment and the verification of the PHOTOELECTRIC EFFECT in both experimental and mathematical concepts (see [Figure M.111](#)).



Figure M.111 Robert Andrews Millikan (1868–1953), in 1917. (Courtesy of University of Chicago Science Series.)

Millikan oil-drop experiment

[atomic, general, nuclear] An atomizer provides a continuous droplet stream of OIL droplets that fall through the central hole of two plates that have an ELECTRIC FIELD (E) applied. An applied continuous beam of X-RAY radiation forms a mechanism for charging the droplets. Charged droplets will be suspended, actually lifted, while the uncharged (neutral) droplet will continue in free fall, reaching the TERMINAL VELOCITY v_g . The balance of the three forces, GRAVITATION, FLOW resistance, and electric field force, will result in a rising velocity of constant magnitude, depending on the electric field velocity (v_E). The experimental design was implemented by Robert Millikan (1868–1953) and coworkers in 1909. The experiment provided the MAGNITUDE of the charge of an electron (q): $q = (k/e)(v_g + v_E)$, where k_S is a proportionality factor derived by GEORGE GABRIEL STOKES (1819–1903) for the flow resistance $F_R = k_S v = 6\pi\eta r v = 18\pi\left\{\eta^3 v_g / 2g(\rho - \rho_a)\right\}$, where η is the VISCOSITY of the resisting medium, r the radius of the body in FLOW (i.e., droplet radius), g the GRAVITATIONAL ACCELERATION, ρ_d the density of the oil, ρ_m the density of the medium, and v the magnitude of PARTICLE velocity (see [Figure M.112](#)).

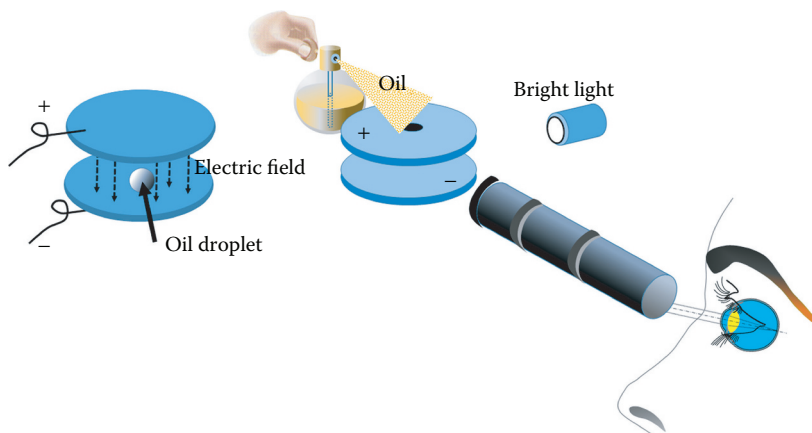


Figure M.112 Millikan's oil-drop experiment.

Minimum dissipation theorem

[fluid dynamics] Theoretical approach in nonequilibrium THERMODYNAMICS to form a prediction of likely steady state situations as well as other dynamical structures that a physical system, specifically pertaining to ENERGY flow and real flow, might exhibit. Helmholtz formulated the minimum dissipation energy principle as the energy difference of a stationary flow of INCOMPRESSIBLE FLUID with respect to FLOW with arbitrary MOTION while containing the same velocity distribution. In 1869, HERMANN VON HELMHOLTZ (1821–1894) stated his principle of least viscous dissipation of kinetic energy. This principle entails that for a steady flow in a viscous fluid, with the small flow velocities on the boundaries of an incompressible fluid, under steady-state conditions, will evolve in currents with turbulent tendencies. This perturbation of the LIQUID flow will evolve in a distribution within which the dissipation of kinetic energy by FRICTION is minimal. The bases for the minimal dissipation of energy is that these fluid motions will be below the threshold for TURBULENCE due to viscous forces. In 1878, Helmholtz applied similar principles to electric currents in a SOLUTION of electrolytes that exhibits a concentration gradient. This balance of forces shows nonequilibrium coupling between forces resulting from electric effects and based on DIFFUSION resulting from the concentration gradient. The reciprocal relation discovered by Helmholtz was later redefined by the Norwegian scientist, chemist, and mathematician Lars Onsager (1903–1976). The original expression of Hermann von Helmholtz in 1868 was later redefined by Onsager in 1931 in terms of a force (F , a hypothetical thermal “force,” which proved the mechanism-of-action for the conduction of heat) as $F = \int_V \Phi dV \xrightarrow{\delta F=0} \text{minimum}$, where $\Phi = 1/2 \sum_{i,j=1}^n R_{ij} J_i J_j$, and J_i and J_j are SCALAR forms of thermodynamic flows and R_{ij} the flow corresponding to the RESISTANCE for a VOLUME (V) outlined by a surface (S). This indicates the viscous dissipation that can be minimized. For the Stokes flow, this relates to the rate of strain within the fluid e_{ij}^s (TENSOR), while the flow velocity is bound by $\nabla \cdot \vec{v} = 0$, where the velocity can be disbanded in two components as $\vec{v} = \vec{u} + \vec{w}$, providing two respective rates of strain components e_{ij}^u and e_{ij}^w as $\int_V e_{ij}^u e_{ij}^u dV = 2 \int_{\partial V} w_i n_j e_{ij}^u dS - 2 \int_V \vec{w} \cdot \nabla P dV$, where P is the local pressure. The second term is negligible by definition under the assumed flow conditions, while the first term reaches zero as the components $w_i = 0$ on the surface. The Dutch mathematician Diederik Korteweg (1848–1941) in 1883 verified Helmholtz’s hypothesis, stating that in any basically connected region, with known boundary velocities, meaning that the squares and products of the velocities of an incompressible viscous fluid may be neglected when small and uniformly distributed, there will be only one solution to the equations for the steady motion, and this solution is always nondiverging and stable.

Minimum energy

[fluid dynamics] Statement by LORD KELVIN (1824–1907) in 1910 pertaining to the fact that an irrotational motion of a LIQUID occupying a simply connected region contains less kinetic ENERGY than any other (rotational or otherwise turbulent) motion corresponding to a mechanism of MOTION that has equivalent normal velocity conditions on the outlying boundary of the system’s domain (e.g., surface of a volume of FLUID in FLOW). A theorem in FLUID DYNAMICS relates the steady state condition to minimum kinetic energy of an ideal fluid. The ideal fluid will be inviscid, incompressible, and irrotational. The SOLUTION provides statements concerning the POTENTIAL FLOW uniqueness. Also known as Kelvin’s minimum energy theorem (*also see* MINIMUM DISSIPATION THEOREM FOR COMPARISON).

Minimum mean square error

[acoustics, computational] In the process of making systematic estimates on behalf of predictions with respect to quantities or making predictions, the use of data obtained from similar systems can be useful but error prone. Certain assumptions or established connects must be made between the unknown and the known systems of values. Choosing the estimate wisely will rely on establishing a minimum mean square error. Combining multiple values that are somehow correlated to another ultimate parameter relies on a process referred to as linear minimum mean square error estimation, applying recursive values to provide the additive error. The estimate can be based on a PROBABILITY distribution ($f_Y(y)$), which is either known or inferred, providing the estimate ($\hat{y}$) for a random variable (Y). For this the minimization process follows, minimize: $\text{ERROR}[(Y - \hat{y})^2] = \int (y - \hat{y})^2 f_Y(y) dy$, which yields the variance σ_Y^2 .

Minimum phase filter

[acoustics, computational, theoretical] Electronic or mechanical (ACOUSTICS) filter based on the fact that the linearity of response to the PHASE of a WAVE is not critical in preserving the waveshape. In this case, we may allow the phase to be arbitrary, or alternatively to define the phase in such a way that the AMPLITUDE response to the process (and inherently the processing algorithm) is easier to match. In SIGNAL PROCESSING, the minimum phase filters are by definition stable due to the fact that the POLES must be inside the unit circle of the defined region of validity. In addition, the inverse filter is also stable when the operator is minimum phase since the function zeros must also be inside the unit circle. Mathematically, minimum phase filters form an algebraic operator group in which the ELEMENTS are formed by respective IMPULSE RESPONSE contributions and the group operation is formed by convolution.

Minimum velocity of water waves

[fluid dynamics] Wavelength- dependent formulation defining the validity of applying the WAVE EQUATION to a problem in the transition from CAPILLARY WAVES to GRAVITATIONAL WAVES. This velocity limit places a threshold on the application of the wave model to be used. Under capillary WAVE MOTION, the SURFACE TENSION has an over powering force influence on the wave description. Generally, water waves with a wavelength less than $\lambda = 0.0173$ m can be considered capillary waves. At this point, the PHASE VELOCITY has a minimum value 0.231 m/s. Note that the velocity of water waves (v) beyond this point is a function of depth (h), as $v = \sqrt{((g\lambda/2\pi) \tanh[2\pi(h/\lambda)])}$, which goes asymptotically to $v = \sqrt{(g\lambda/2\pi)}$ for deep water (see Figure M.113).

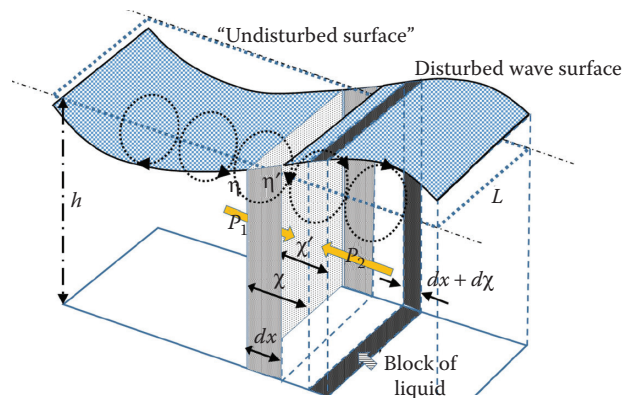


Figure M.113 The velocity of waves on water (liquid in general) is a function of the depth h to $h + \eta$ with respect to wavelength (i.e., prone to dispersion) while the water surface moves down the “slice” of water to the bottom of the ocean or river will change in “thickness” dx to $dx + d\chi$ with respect to the raised water surface, providing for the slice of width L in continuity: $Lhdx = L(h + \eta)(dx + d\chi)$, which yields $\eta = -h(\partial\chi/\partial x)$, converted into the wave-equation: $\partial^2\chi/\partial t^2 = gh(\partial^2\chi/\partial x^2)$, which provides the wave velocity $v = \sqrt{gh}$, g the gravitational acceleration.

Mini-sparker

[acoustics, computational, geophysics] Agitation source in a geophysical seismic model, primarily based on mechanical pulse response. The concept also applies to computational modeling of the response of hydrophones in deriving the WAVE diffraction response function and in calibration. The mini-sparker will have a frequency response (i.e., spectral profile) and pulse shape. On a smaller scale, the process applies to sonic imaging in marine applications, such as submarine echo ranging.

Mirror

[general, mechanics, optics] Device that forms an IMAGE of an object by means of REFLECTION. Optical and acoustical mirrors can be concave with a FOCAL POINT on the side of the source, or convex, where the focal point is on the opposite side of the device surface with respect to the source. Generally concave will form either a virtual (when the object is placed at a DISTANCE closer than the focal point) or a real image, whereas convex mirrors and flat mirrors always form a virtual image. The focal point (f) of a curved mirror is half the radius of curvature (R): $f = R/2$. The image magnification (M) is the ratio of the image size (i) to the object size (o): $M = i/o$. Parabolic mirrors provide a mechanism to generate a parallel beam from a source with finite dimensions placed in the focal point. The headlights of an automobile are most known for their parabolic mirror shape. Alternatively, the collection of waves from a not perfectly parallel on-axis source to form an image in the focal point of a parabolic mirror will be more likely to form a small spot size than a spherical mirror, providing corrections to SPHERICAL ABERRATIONS. Radio antennas provide the best example of parabolic collection devices, specifically requiring a less than perfect on-axis alignment. Only an infinitely small source will produce a parallel outgoing beam when placed in the focal point of a spherical mirror. Mirrors are used to direct the path of SOUND waves, RADIO and television waves and optical rays. The exercise of outlining the formation of an image resulting from a source configuration and a mirror design is referred to as ray tracing, and can be performed with pen and paper or by computer simulations. In a complex system, both lenses and mirrors can be applied. An aspherical mirror is not symmetric as compared to a standard parabolic mirror. One specific example of an aspherical mirror is found on the passenger side of the car (objects are closer than they appear).

Mirror formula

[general] Formula describing how the size of the object (o) and the IMAGE size (i) are linked by the radius of curvature of the reflecting object (R_{reflect}) used to generate the image: $1/o + 1/i = 2/R_{\text{reflect}}$, note that a converging MIRROR (concave) has positive radius, and a convex mirror has negative radius, where a positive image reflects a real image and a negative image means virtual.

Mirror nuclei

[atomic, nuclear] Atomic nucleus that is constructed of a respective number of neutrons and protons that, in comparison with another nucleus, are mutually interchanged; the number of protons may match the number of neutrons of the mirror and vice versa. The mirror nuclei are generally isotopes, such as ^{14}O and ^{14}C , and may be short-lived. Mirror nuclei will have a mass difference that is the result from the difference in ENERGY (E) configuration between the two nuclei, expressed by the respective energy states (s_i , with respect to GROUND STATE s_0), and specifically the difference in the total population assembly (n , representing the GREEN'S FUNCTION of occupation for the new with respect to the old nucleus for an ISOTOPE; the energy content of the changed state of the isotope [the "MIRROR"] is compared to the indigenous state of the original stable nucleus) of energy states: $\Delta E = a^2 \sum_{s_j s_i} \Gamma_{s_j s_i}^{s_0 s_0} (n'_{s_i} - n_{s_i})$, where $\Gamma_{s_j s_i}^{s_0 s_0}$ represents the Coulomb interaction on an elementary PARTICLE level for the constituents of the NUCLEUS.

Mitochondria

[biomedical, energy] Specialized cellular component (organelles) in living cells that use oxygen. The living CELL (eukaryotic) has a nucleus. The mitochondria have the sole responsibility for the production and storage of ENERGY to make the cell operate, specifically the formation of ADENOSINE TRIPHOSPHATE (ATP) synthesis. In the process executed by the mitochondria, OXIDATION of simple organic compounds produces electrons generated during a chain of four membrane-bound enzymes, housed in the MEMBRANE. The reduction process is referred to as the electron transport or respiratory chain. The final stage involves the reduction of oxygen to produce water, generating an electron movement that builds a proton gradient across the membrane. The PROTON gradient drives the ATP generation as a TURBINE. The mitochondria additionally house several metabolic enzymes that support the survival of the cell. The inner structure of

the mitochondrial membrane uses surface enlargement for optimal performance, since all energy processes take place in the membrane itself, next to the storage in the LIQUID of the organelle. The outer membrane consists of a lipid bilayer that is freely permeable to a broad range of molecules. The permeability to the molecules, specifically smaller than about 5000 daltons, results from the abundance of a channel-forming protein called porin. Some of the enzymes in the mitochondrial FLUID also assist in the production of phosphates that can be converted to ATP, by phosphorylating other nucleotides. Mitochondria have a diameter ranging from 0.5 to 1.0 μm and length ranging from 1 to 10 μm , depending on the type of cell in the biological system (see Figure M.114).

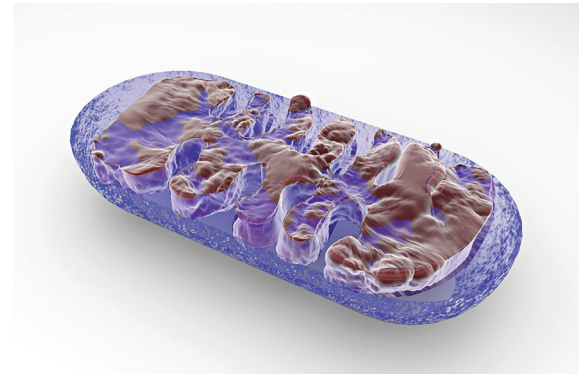


Figure M.114 Microscopic view of a mitochondria in a biological cell.

Mixing

[biomedical, chemical, thermodynamics] Combining fluids and solids. When solids, liquids, and gases are mixed their respective thermodynamic properties as well as that of the combined system will be altered. Mixing a SOLVENT with one of more solutes, or blending constituents in different phases, to form a single PHASE is mixing. Dissolved oxygen in BLOOD forms a mixture as does coffee with milk and sugar. Atmospheric AIR is a mixture of nitrogen, oxygen, argon, and TRACE elements as well as water VAPOR, all acting as ideal gases. The Gibbs ENERGY of a mixture forms the sum of the fractional components, expressed by means of the number of moles (n) and the respective partial molar Gibbs energy ($G^* = \mu_{\text{chem}}$; which is equal to the chemical potential): $G = \sum n_i G_i^*$. Based on the fractional contribution (n_i/n) the change in Gibbs free energy due to mixing is $\Delta G|_{\text{mix}} = nRT \sum_i (n_i/n) \ln(n_i/n)$, with GAS constant: $R = 8.3144621(75) \text{ J/Kmol}$ and the process at temperature T . In case the mixture is for gases at pressure P_i , the Gibbs energy for the mixture can be written as $\Delta G|_{\text{mix}} = \sum_i n_i (\mu_{\text{chem},i} + RT \ln P_i)$. Similarly, the entropy change as a result of mixing is $\Delta S|_{\text{mix}} = nR \sum_i (n_i/n) \ln(n_i/n)$. The enthalpy change is provided by $\Delta H|_{\text{mix}} = \Delta G|_{\text{mix}} + T \Delta S|_{\text{mix}}$. In all cases, the entropy of the mixture will be greater than that of the components separately. The first-order derivative of the Gibbs free energy provides a negative, implicating that mixing is generally spontaneous. The second-order derivative of the entropy will also always be negative, indicating that the mixture will be adverse to phase separation and supports miscibility (i.e., no preferential mixing ratio) (also see **RAOULT'S LAW**, **HENRY'S LAW**, **FUGACITY**, and **GIBBS–DALTON MIXTURE**).

Mixing length (ℓ_m)

[fluid dynamics] In FLUID flow the mixing length describes the DISTANCE (ℓ_m) over which the momentum transfer takes place within a NEWTONIAN FLUID thin shear BOUNDARY LAYER by means of TURBULENCE Reynolds stresses under the influence of Boussineq eddy viscosity (mathematician from France, Joseph Valentin Boussineq [1842–1929]), and is proportional to the half-width of the shear layer (ℓ_s) for free SHEAR FLOW. The ratio of shear layer to mixing length for specific objects is, for instance, $\ell_m = 0.09\ell_s$ for plane JET flow, and $\ell_m = 0.075\ell_s$ for circular jet flow. The concept was introduced by LUDWIG PRANDTL (1875–1953) in. The eddy VISCOSITY MODEL is described as $-u'_i u'_j = \eta_T ((\partial U_i / \partial x_j) + (\partial U_j / \partial x_i)) - 2/3 \delta_{ij} \epsilon_{\text{Boussineq}}$

where $u'_i u'_j$ is the average of the product of the horizontal and vertical components, known as REYNOLDS STRESS, $\eta_T = \ell_m'^2 |\partial U_k / \partial x_k|$ is the eddy viscosity, measured in the direction of FLOW, u'_n the FLOW velocity components in the respective dimensional reference frame with components ($n = (i, j, k)$), U_n is the, δ_{ij} the Kronecker delta function, and $\kappa_{\text{Boussinesq}} = |u'_m u'_m|/2$. Ludwig Prandtl (1875–1953) proposed that the mixing length is linked to the eddy viscosity and the turbulent velocity as $\eta_T \sim u \ell_m$; furthermore, Prandtl postulated a link between the flow velocity component and the turbulent velocity component as $u \sim \ell_m |\partial U_j / \partial x_j|$. (Note: For incompressible flow of a homogeneous fluid the flow velocities can be split into a mean part $[u_i]$ and a fluctuating part $[u'_i]$ using Reynolds decomposition, defined as $u_i = u_i + u'_i$.)

Mixing time ($\theta_m = t_m/t_c$)

[chemical, computational, mechanical, thermodynamics] Dimensionless number yielding the ration between the time to phenomenological time frame: t_m , and the time to pass through one CIRCULATION loop, cycling time: t_c . In computational PHYSICS this refers to the relative time that RANDOM WALK phenomena will intersect. In MECHANICS it relates to the time frame needed to achieve a set level of homogeneity during physical joining of two or more constituents. In THERMODYNAMICS the mixing time describes the time span in which a phenomenon will evolve into an irreversible process and the ENERGY transitions involved in the time lapse. In computational physics the MARKOV PROCESS will reach a predefined form of homogeneity in PROBABILITY of the distribution of states at the end of the mixing time, also called MARKOV CHAIN MIXING TIME.

MKSA system

[general] System of units based on the elementary parameters: length, meter (m); mass, kilogram (kg); time, second (s); and current (charge flow), AMPERE (A). This makes the Coulomb unit (C), for charge $C = As$. The unit volt (V) for electric potential becomes $V = kg/m^2 s^2 C = kg/m^2 s^3 A$.

M

PHYSICAL PARAMETER	UNIT	SYMBOL	DIMENSION	LOGISTIC PARAMETER	FUNCTION
Angular momentum	kgm^2/s	L	ML^2T^{-1}		$\vec{L} = \vec{r} \times \vec{p}$
Angular velocity	rad/s	ω	T^{-1}		$\omega = \frac{d\theta}{dt}$
Capacitance	Farad: F	C	$M^{-1}L^{-2}T^{-2}Q^2$		$Q = CU$
Charge	Coulomb: $Coul$		Q	q	elementary
Current	Ampere: A	I	$T^{-1}Q$		
Energy, work	Joule: J	E,U,W	ML^2T^{-2}		
Force	Newton [N]	F	MLT^{-2}		
Inductance	Henry [H]	L	ML^2Q^{-2}		$V = L \left(\frac{dI}{dt} \right)$
Length	Meter [m]	ℓ	M		elementary
Magnetic flux	Weber [Wb]	Φ	$ML^2T^{-1}Q^{-1}$		$\Phi = \int \vec{B} \cdot d\vec{S}$
Magnetic induction	Tesla	B	Wb/m^2		
mass		m			
Momentum	kgm/s				$p = mv$

(Continued)

PHYSICAL PARAMETER	UNIT	SYMBOL	DIMENSION	LOGISTIC PARAMETER	FUNCTION
Potential, voltage, emf	Volt [V]	$U, \varepsilon_{emf};$ emf			$U = \frac{\Delta E}{q}$
Resistance	Ohm [Ω]	R	$ML^2T^{-1}Q^{-2}$		
Time	Second [s]	τ	T		
Velocity	m/s	v	LT^{-1}		$v = \frac{ds}{dt}$

Möbius, August Ferdinand (1790–1868)

[astrophysics/astronomy, computational, mechanics] Mathematician and astronomer from Germany, the Prussian Empire. Möbius is best known for his contributions to analytic geometry and his work in topology. Möbius designed the belt that has only “one surface,” the MÖBIUS BAND, or Möbius strip (see [Figure M.115](#)).



Figure M.115 August Ferdinand Möbius (1790–1868).

Möbius band

[computational] Strip of material that has a twist in it so that one can follow the surface around 720° and return to the same point, while a 360° passage will not cross with any points that were passed on the track. This is referred to as an infinite band, or strip, described by AUGUST FERDINAND MÖBIUS (1790–1868) (see [Figure M.116](#)).



Figure M.116 Illustration of the Möbius band concept.

Mode conversion

[acoustics] Sound traveling in a solid material can convert its ENERGY into a different format. One example is a longitudinal (e.g., acoustic) compression wave (P-WAVE, i.e., pressure wave) incident on an interface at an ANGLE. Due to the MICROSCOPIC interaction the longitudinal displacement can cause PARTICLE movement in the transverse direction, which initiates a shear wave (S-wave), or transverse wave (*also see* LAMB WAVE, EVANESCENT WAVE, or RALEIGH WAVE). Nonperpendicular wave incidence on an interface between two media with different acoustic impedances will also generate mode conversion. S-waves and P-waves can be transformed into each other at discontinuities, such as rock-faces in soft crust during an EARTHQUAKE. S-waves can be transmitted in polarized form. Acoustic S-waves were described in the 1800s based on the stress–strain relationship for an isotropic solid, providing the stress relation: $\tau_{ij} = \lambda_L \delta_{ij} \epsilon_{ii} + 2\mu_L \epsilon_{ij}$, where μ_L and λ_L are the Lamé coefficients, introduced by GABRIEL LAMÉ (1795–1870), $\epsilon_{ij} = (1/2)(\partial_j v_i + \partial_i v_j)$ and respectively $\epsilon_{ii} = \partial v_i / \partial x_i$ strain, v_i the velocity in the direction i , ∂_i the gradient change normal to the MOTION, and δ_{ij} the Kronecker delta function. This transforms into the SEISMIC WAVE equation: $\rho(\partial^2 \vec{v} / \partial t^2) = (\lambda_L + 2\mu_L) \nabla(\nabla \cdot \vec{v}) - \mu_L \nabla \times (\nabla \times \vec{v})$, where ρ represents the density of the medium.

Mode-locked laser

[energy, optics, quantum] Laser operating under pulsed conditions that use either an active ELEMENT (an optical modulator: e.g., crystal such as KTP) or a nonlinear passive element (a absorber that can saturate, holding the excitation process and subsequent release followed by a very high ENERGY burst of photons at the wavelength of the medium) in the laser cavity, and are capable of producing extremely short pulses, in the order of femto- and picosecond duration. The spectral width of mode-locked lasers is broad due to the condition linking frequency bandwidth ($\Delta\nu$) to time of light pulse (Δt) as $\Delta\nu\Delta t \geq 1/4\pi$. Active mode-locking can be achieved by integration of either an electro-optic or an acousto-optic modulator in the laser cavity. Examples of active modulators are a Mach–Zehnder integrated optic modulator, or a semiconductor electro-absorption modulator. If the modulation frequency is synchronized with the resonator path of the laser cavity the laser will produce light only at the resonant convergence maxima. Technically, the operational mode of the modulator needs to lock-in with the preferred laser mode (see Figure M.117).

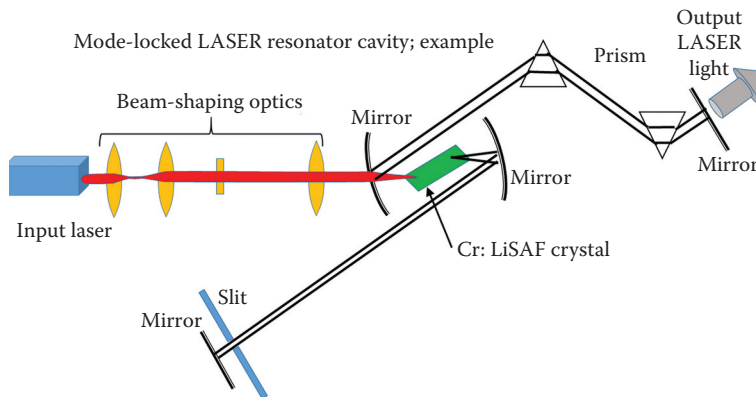


Figure M.117 Graphical representation of the Mode-Locked LASER concept.

Moderator

[nuclear] Rod in a nuclear power reactor that moderates the rate of degradation of URANIUM (^{235}U), by means of slowing down the released fast neutrons, created during the disintegration that can initiate the expedited fission DECAY of the unstable uranium to ^{236}U , under $^{235}\text{U} + n_{\text{slow}} \rightarrow ^{236}\text{U} \rightarrow X + Y + \nu n_{\text{fast}}$, where the reaction is sustained when the constant $\nu_{\text{neutron}} > 1$, the MULTIPLICATION FACTOR, and X and Y are short-lived reaction products. The reaction is regulated by absorbing neutron in carbon rods, known as control rods, regulating the quantity ν_{neutron} . Keeping in mind that naturally occurring uranium (as used in the fuel

rods) only consists of 0.72% ^{235}U , with the balance ^{238}U ; which converts to ^{239}U under absorption of a NEUTRON, thus depleting the FISSION process, however the reaction CROSS SECTION is less than 1 barn $\cong 10^{-28} \text{ m}^2$, while the cross section for ^{235}U is 582 barn. Generally for uranium the process is well controlled for $v_{\text{neutron}} = 2.47$, while for PLUTONIUM (^{239}Pu) $v = 2.91$ (see Figure M.118).

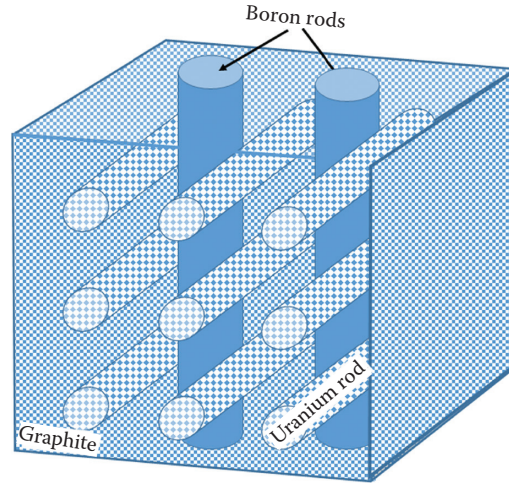


Figure M.118 Boron moderator rods in uranium nuclear power reactor.

Modes of vibration

[general, mechanics] The geometrical deformation patterns in a vibrating MEMBRANE or disk, such as percussion instruments (drums and timpani), as well as in the working of the eardrum. The WAVE EQUATION in two dimension will provide the superposition of multiple waves with different or equal wavelengths traveling or standing in various directions within the vibrating surface: $\partial^2 u / \partial t^2 = v^2 \left((\partial^2 u / \partial x^2) + (\partial^2 u / \partial y^2) \right) = v^2 \left((\partial^2 u / \partial r^2) + (1/r) (\partial u / \partial r) + (1/r^2) (\partial^2 u / \partial \theta^2) \right)$, where u signifies a field MAGNITUDE or a displacement in a Cartesian coordinate system or in a cylindrical coordinate system, and v is the velocity of propagation of the transverse or LONGITUDINAL WAVE in the medium, since the wave may also be confined to a thin layer of gaseous medium. The classification of the EIGENFUNCTION solutions for each geometry provides an indication of the wave form on the surface. The number of modes are a function of the SURFACE TENSION, the diameter (characteristic lengths; the larger the characteristic length the greater the number of modes), elastic modulus, and thickness. These all provide the boundary conditions to the acoustic problem. The AMPLITUDE for higher modes for a small diameter drum will be proportionally less and become negligible (i.e., higher modes become critically damped) (see Figure M.119).

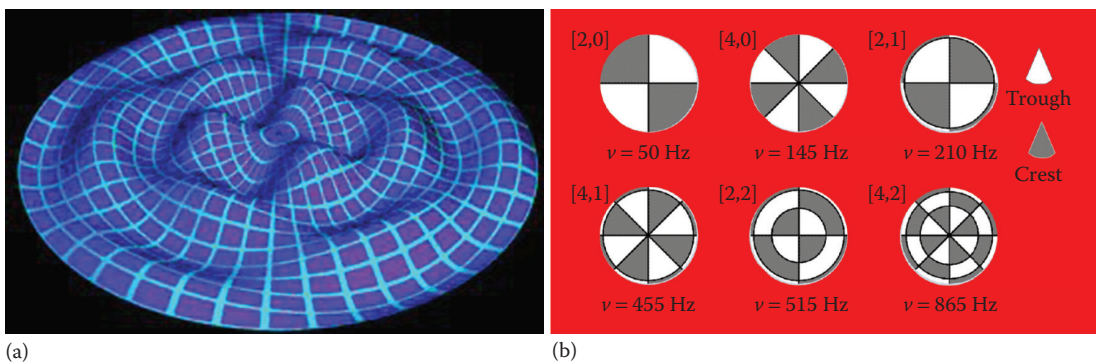


Figure M.119 (a) Outline of some of the simpler modes of vibration for a circular plate. (b) Various, selected (not all) vibrational modes for a circular skin under tension (i.e., drum surface) or metal (steel drum).

Modulus decay

[energy, fluid dynamics, quantum] Generic cosmic SCALAR fields in the GRAND UNIFIED THEORY have consequences which can be analyzed in the form of moduli which will primarily DECAY through gravitationally suppressed interactions only. This generates a production mechanism of gravitinos (the hypothetical GRAVITATION particles) resulting from moduli decay.

Modulus of elasticity (Y)

[general, mechanics] The ratio of the stress to the strain. Description of the elastic properties of linear objects such as cables, shafts, or structural columns subjected to stretch or compression. ELASTICITY is a material property that will result in the restoration to the original shape of the object after distortion (*see* HOOKE'S LAW). Also referred to as the “Young's modulus” of the material.

Modulus of rigidity

[mechanics] Coefficient of ELASTICITY with respect to an applied shearing force, used in materials science $G_{\text{rig}} \equiv \tau_{xy}/\gamma_{xy} = (F/A)/(\Delta x/l) = Fl/A\Delta x$. Defined as the ratio of SHEAR STRESS (the force $[F]$ per unit area (A) : τ_{xy}) to the displacement (Δx) per unit length (l) of the object (i.e., the shear strain: γ_{xy}), derived from the slope of a stress–strain curve. It is also known as shear modulus.

Moens, Adriaan Isebree (1846–1891)

[fluid dynamics] Scientist and physician from the Netherlands. When focusing his research on the principles of arteriosclerosis and vascular stiffness his work produced the foundations for the mathematical description of pulse propagation in flexible tubes in 1878. His collaborator was the mathematician from the Netherlands, Diederik Korteweg (1848–1941). Moens was a close friend of WILLEM EINTHOVEN (1860–1927), the scientist from the Netherlands who introduced the acquisition of the electrocardiogram (*see* Figure M.120).



Figure M.120 Adriaan Isebree Moens (1846–1891). (Courtesy of Museum Boerhaave.)

Moens–Korteweg equation

[fluid dynamics] *See* MOENS–KORTEWEG VELOCITY.

Moens–Korteweg velocity

[computational, fluid dynamics] Mathematical description of a FLOW process in a flexible tube, such as a BLOOD vessel or rubber tube (e.g., oil filling, gasoline pumping, etc.), allowing for local expansion in the cross-sectional flow area. The principle was introduced by the Dutch team ADRIAAN ISEBREE MOENS (1846–1891) and Diederik Korteweg (1848–1941). The elastic WALL expansion process produces a WAVE propagation that travels with a propagation velocity: $v_{\text{MK}} = \sqrt{(E_Y \tau_{\text{wall}}/2R\rho)}$, where E_Y represents the elastic modulus of the tube, τ_{wall}

the local wall thickness, R the radius of the tube, and ρ the LIQUID medium density; under the assumption that EXPANSION is isotropic and responds in isovolumetric change with respect to pulse pressure. It is also known as the MOENS–KORTEWEG EQUATION. This approach is an extension to the NAVIER–STOKES EQUATION.

Moiré pattern

[acoustics, fluid dynamics, optics] The term Moiré has its origin in a woven fabric pattern that creates an impression of three-dimensional depth and speaks to the imagination. The original silk textile weave resembles water waves, dating back to a process found in the fourteenth or fifteenth century called “marmoreus,” later (mid-sixteenth century) interpreted as “mohair.” In the mid-seventeenth century his was interpreted in French as “mouaire.” In the early nineteenth century the term made it back to English as “moire.” Form of ALIASING, where two identical patterns are overlaid at a slight ANGLE to each other whereby false patterns can be observed in an IMAGE. The patterns can be produced by optical aberrations, defects in instrumentation, inferior quality of optical ELEMENTS (lenses, windows), or intentionally resulting from illumination of an uneven surface through a grid pattern where the LIGHT SOURCE is placed at an angle from the observer. The latter will create irregularities in the cross pattern based on the elevation of the uneven surface observed behind the multislit screen. A picket fence can provide the conditions to observe the topography of a flowerbed and grass field while the Sun illuminates through the fence at great ZENITH ANGLE (with respect to the normal). For SOUND, the overlap of two waves can result in a “beat” that is the consequence of the differences between two patterns. In moving patterns, the beat of light and dark also has a beat that is associated with the velocity at which the two patterns move with respect to each other. An optical Moiré pattern can also result from the limitations in RESOLUTION of the recording device with respect to the spatial frequency of a pattern under observation, which can be the EYE looking at a fine line pattern (see Figure M.121).

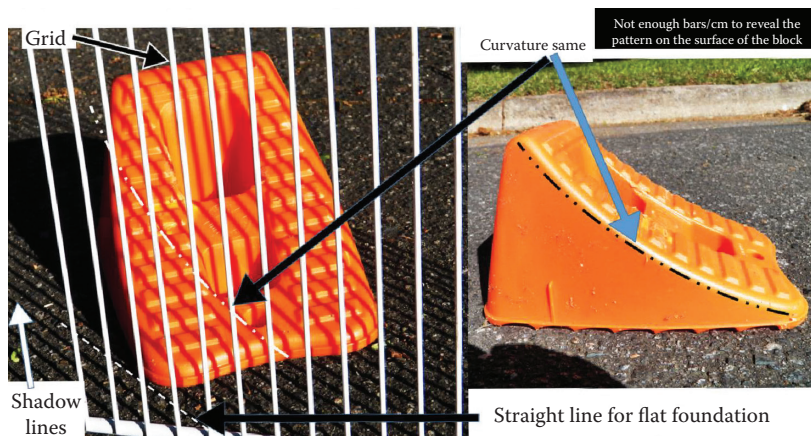


Figure M.121 Moiré pattern. The fringe interference pattern spatial density can be used to identify elevation when a line pattern is projected on an uneven surface and viewed through a screen with the same spatial frequency as the pattern emerging from the projector, without the requirement of stereoscopic vision.

Moist air

[thermodynamics] Quantification of the amount of water vapor in the AIR (see RELATIVE HUMIDITY, ABSOLUTE HUMIDITY, and SPECIFIC HUMIDITY).

Molar heat capacity (c_m)

[atomic, thermodynamics] Quantity of HEAT (Q) required to produce a temperature (T) rise in a quantity of substance, measured in moles (n) of chemical constituents: $c_m = (1/n)(dQ/dT)$, expressed in J/mol°C, which is, for instance, $c_m^{\text{H}_2\text{O}} = 75.3$ J/mol°C and $c_m^{\text{Gold}} = 25.4$ J/mol°C. This is very similar to the SPECIFIC HEAT of a medium, quantified by mass, which has the following values, at constant pressure $c_p^{\text{H}_2\text{O}} = 4180$ J/kg°C and $c_p^{\text{Gold}} = 130$ J/kg°C.

Molar mass

[thermodynamics] Mass associated with a MOLE of atoms, ions, or molecules quantified by the number of components expressed by AVOGADRO'S NUMBER.

Molding stresses

[acoustics] Residual stress resulting from shape formation in a mold. Residual, or molding stress, is a process-induced stress, encapsulated in a molded part. The stress can result from either FLOW during injection molding or thermal effects (cooling [thermal gradients] or curing related). When the molding stress is greater than the internal COHESION forces the part will warp upon ejection from the mold.

Mole

[atomic, biomedical, chemical, general, thermodynamics] Unit to express the number of atoms, electrons as well as ions and specifically molecules in a volume of medium, either dissolved or as dry mass. The carbon ATOM was initially used to quantify the number of atoms in a mass yielding that 12 g of carbon consists exactly of one mole of carbon [^{12}C] atoms. The number of specific items in 1 mole is defined by the AVOGADRO NUMBER ($N_A = 6.02214078 \times 10^{23} \pm 1.8 \times 10^{16}$ [atoms/gram] or [molecules/gram] [2011 definition]), representing $6.02214078 \times 10^{23} \pm 1.8 \times 10^{16}$ atoms of carbon-12 in 12 g of carbon substance. The definition of molecular mass and quantity of substance dates back to 1805, when JOHN DALTON (1766–1844) published the first table of atomic weights.

Molecular band

[atomic, chemical, nuclear, optics, thermodynamics] Absorption lines observed when a pure substance of molecular emulsion is illuminated by broadband ELECTROMAGNETIC RADIATION. Similarly, during excitation (heating or electric current as well as other means of ENERGY delivery), the spectral emission lines comprise a pure substance of single molecular composition. The “empty” orbital electron bands are separated from the “occupied” electron orbital bands in atomic and molecular structure by the FERMI ENERGY (see Figure M.122).

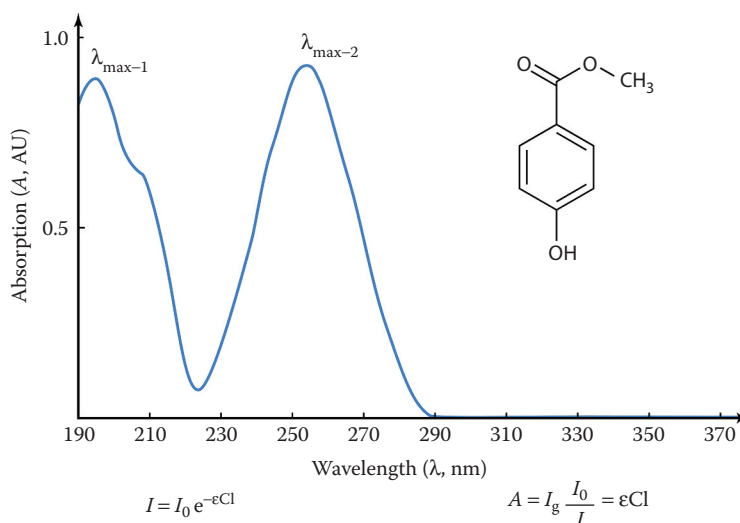


Figure M.122 Molecular absorption spectrum for the chemical compound Paraben.

Molecular beam

[atomic, nuclear] Stream of molecules ejected within a small **SOLID ANGLE**, moving in the same general direction. The emission of molecules can be through an evacuated chamber or from a pressure **NOZZLE**. Due to the essentially one-directional **MOTION** of the atoms, ions, or molecules, specific properties can be studied under deflection by electric and/or **MAGNETIC** fields. The molecular beam may be directed onto a target, consisting of **GAS**, a solid, or intercept an alternative beam of atoms, ions, or molecules. Molecular beams are inherently of low density to avoid collisions.

Molecular beam epitaxy

[computational, fluid dynamics, mechanics, solid-state, thermodynamics] A specific process used in the formation of crystal structure invented at the Bell Laboratories in the late 1960s and is used in the formation of transistors and other electronic components. The **EPITAXIAL GROWTH** process requires high or ultrahigh **VACUUM** conditions and slow deposit rate, significantly less than 1 nm/s, forming a single crystalline layer on a formed or existing crystalline substrate.

Molecular diameters (σ_{molec})

[nuclear] Based on the van der Waals equation, the “covolume” component, $b = 4N_aV$, with N_a **AVOGADRO'S NUMBER** and V the volume of the **MOLECULE**, can be used to derive the size of the molecule in a **GAS**, when taking the volume of one molecule ($V_{\text{molec}} = (4/3)\pi\sigma_{\text{molec}}^3$) when dividing by the Avogadro's number based on the value of b . In the **KINETIC THEORY** of gases the molecular diameter can be used to define the **VISCOSITY**: $\eta = 5/(16\sigma_{\text{molec}}^2)(m\kappa T/\pi)^{1/2}$, where κ is Boltzmann's constant, T the temperature of the gas, and m the mass of the molecule of the gas, assuming that the molecules behave as hard spheres.

Molecular dynamics

[computational] Theoretical study of the physical movement of atoms and molecules by means of simulation of an N -body interaction. The particulate (atoms and molecules) trajectories are derived from **NUMERICAL** solutions to Newton's **EQUATIONS OF MOTION** for a system of interacting units. The forces between the particulates and the acting potential **ENERGY** result from molecular mechanic force field definitions.

Molecular heat

[atomic, nuclear] Heat capacity per **MOLE** for a pure **ELEMENT** of material: amount of heat required to raise the temperature of 1 mole of a substance 1 K (*also see* **MOLAR HEAT** and **HEAT CAPACITY**).

Molecular motion

[nuclear] See **BROWNIAN MOTION**.

Molecular spectra

[atomic, nuclear] See **MOLECULAR SPECTROSCOPY**.

Molecular spectroscopy

[atomic, quantum, solid-state] Under atomic **SPECTROSCOPY** the examination can be based on a gaseous state under electric discharge that separates the atoms into neutral or charged atoms. Alternatively, the **GAS** may be molecular in composition and irradiated by an external excitation source of **ELECTROMAGNETIC RADIATION**. The molecules undergo **ENERGY** transitions based on **GROUND STATE** excitation or return. In general three excitation processes can be distinguished: electronic excitation, vibrational excitation, and rotational excitation, specifically due to the fact that the **MOLECULE** may be asymmetric. For a diatomic molecule the Hamiltonian (H) for the **MOTION** wavefunction approach can be written as (assuming that

the rotational excitation is relatively small compared to the first two):

$H = -(\hbar/2m_1)\nabla_1^2 - (\hbar/2m_2)\nabla_2^2 + V(r_{12})$, where ∇_i^2 is the second-order derivative with respect to the coordinates of nucleus 1 or 2 respectively, m_i the respective atomic/nuclear masses of the molecular constituents, $V(r_{12})$ the electric potential between the two components (both atomic and nuclear), and $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ Planck's constant. This will yield the following SOLUTION for the energy levels that can be identified by spectroscopic analysis: $E = (v_{\text{vib}} + 1/2)\hbar\omega + (J(J+1)\hbar^2)/2\mu_m r_0^2$, where $v_{\text{vib}} = 0, 1, 2, \dots$ the vibrational QUANTUM number, ω the vibrational frequency (the VIBRATION frequency can be associated with a "spring" phenomenon in molecular attraction), $J = 0, 1, 2, \dots$ the rotational QUANTUM number (with transition selection rule: $\Delta J = \pm 1$), $\mu_m = m_1 m_2 / (m_1 + m_2)$ the REDUCED MASS, and r_0 the average nuclear separation. A diatomic molecule can for instance be hydrogen chloride (see Figure M.123).

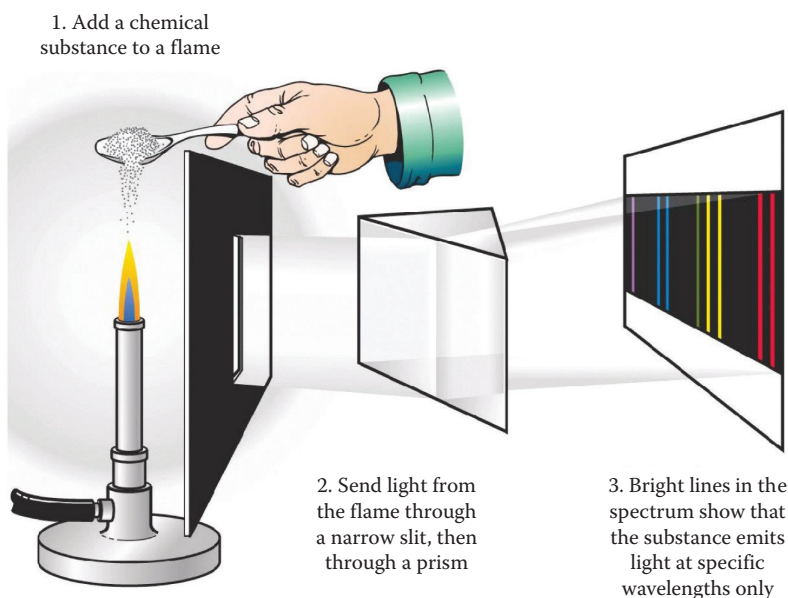


Figure M.123 Illustration of early design flame-spectroscopy device for use on molecular gasses, salts, and other chemicals.

Molecular weight

[thermodynamics] The sum of all atomic weights of the constituent atoms forming a MOLECULE.

Molecule

[atomic, biomedical, chemical, general, thermodynamics] The smallest chemical unit of material that has all the characteristics of the substance or ELEMENT in mass quantity (i.e., it can exist by itself while

retaining all the properties of the original homogeneous substance; see Figure M.124). The molecule consists of two or more atoms that are held together by covalent attractive forces to form a stable unit with no externally observable charges, the molecule is electrically and electronically neutral. The most well know molecules are oxygen (O_2) and WATER (H_2O).

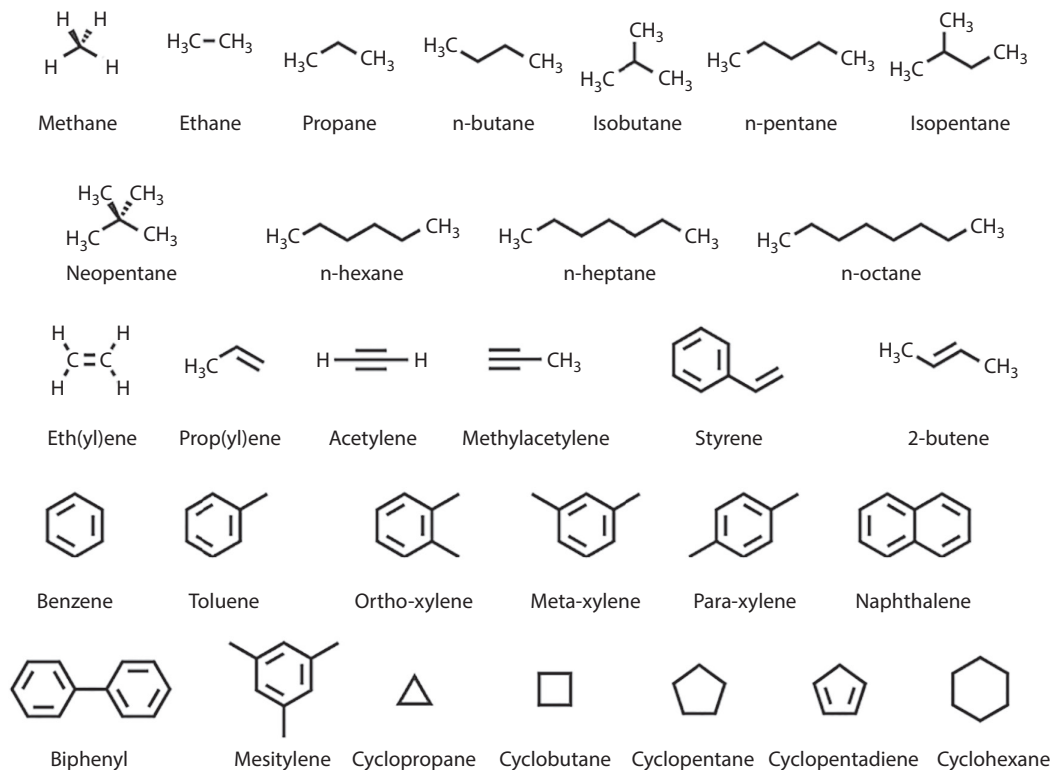


Figure M.124 Graphical representation of the molecular structure of various hydro-carbon molecules.

Mollier chart

[thermodynamics] Graphical representation of the interconnecting relationships between temperature, moisture content, and respective entropy and enthalpy of composite gases, such as the ATMOSPHERE (composed of nitrogen, water vapor, oxygen and ozone, argon, neon, helium, methane, krypton, hydrogen, nitrous oxide, and xenon). The basic Mollier chart is used to plot the total heat against entropy. The chart was designed by the German physicist Richard Mollier (1863–1935) in 1904. The Mollier chart forms an elementary design tool to account for air–grain–moisture system in a malting process, refrigeration (performance analysis of VAPOR compression systems), and is also used by power station engineers in, for instance, the steam cycle. The chart shows ENTHALPY (H) with respect to internal ENERGY U , as well as

pressure P and volume V . The Mollier chart also applies to the Rankin cycle (*also see* PSYCHROMETRIC CHART, of which the Mollier diagram is a variant) (see [Figure M.125](#)).

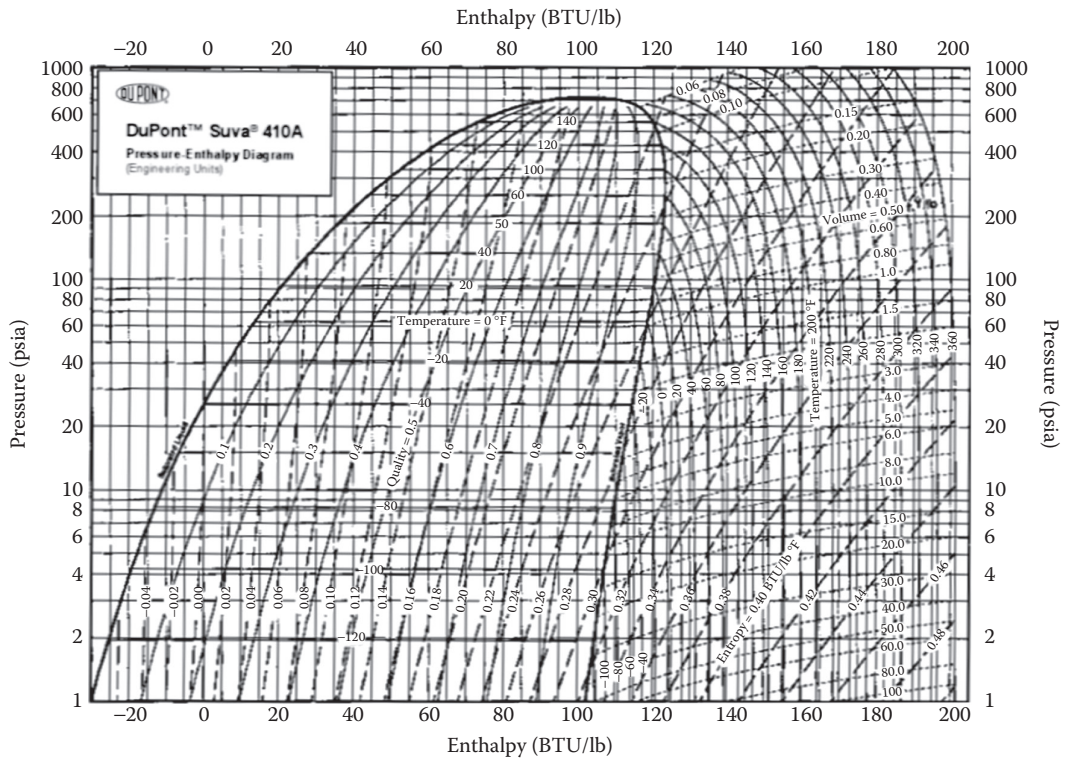


Figure M.125 Mollier entropy chart for 410 refrigerant. (Courtesy of DuPont®.)

Molniya orbit

[astrophysics, general, mechanics] Highly eccentric orbit of Russian (USSR—Union of Soviet Socialist Republics) (in Russian: Союз Советских Социалистических Республик: “СРСС”) satellites at an azimuth inclination of 63.4° with orbital period of one-half of a sidereal day (sidereal time is based on the earth’s rate of rotation with respect to the fixed observable stars, used by astronomers to track the position of their TELESCOPE). These satellites have been in orbit since the 1960s. In Russian the word Molniya stands for “LIGHTNING.” In this configuration the SATELLITE spends the majority of time over the northern

hemisphere, reaching its highest orbital DISTANCE (apogee) of 40,000 km. For continuous coverage of the northern hemisphere a minimum of three Molniya satellites will be required. Satellites of this type can be used for communication as well as espionage (see [Figure M.126](#)).



Figure M.126 Representation of the Molniya orbit on postage stamp.

Moment arm

[biomedical] The perpendicular DISTANCE from line of force application with respect to the axis of rotation. This applies to the rotational MOTION of a joint in a biological vertebrate animal produced by the torque applied by musculoskeletal attachment, such as the elbow and the knee (see [Figure M.127](#)).



Figure M.127 The moment arm of the chimpanzee, proving a powerful lever, much stronger than the human elbow (a chimpanzee will easily overpower a human).

Moment coefficient

[fluid dynamics] Heuristic method used to quantify the aerodynamic forces on an object under FLUID flow conditions. The general form for a regular object (e.g., rod, WING, plate, or a bullet) is $C_m = \alpha_1 / (\text{Re}^{\alpha_2} [1 - \{\alpha_3 \text{Re}^{\alpha_4} \text{arcsinh}(\alpha_5 \text{Re}^{\alpha_6})\}])$, with α_i constants that are dependent on the conditions and shape and size, and Re is the REYNOLDS NUMBER of the object subjected to FLOW. For a sphere this yields $C_{m_{\text{sphere}}} = 8g / \text{Re}_{\text{sphere}}$, where $\text{Re}_{\text{sphere}}$ is the Reynolds number of the sphere in the flow, and g the GRAVITATIONAL ACCELERATION. The method is of particular relevance under transverse Blasius BOUNDARY LAYER flow. One specific example of interest refers to the aerodynamic aspect of a bullet in flight. There are several moments involved that describe the role, yaw and trajectory of a bullet, defined as follows: rolling moment coefficient— $C_{\ell} = \mathcal{L} / q S d$, where $\mathcal{L}$ is the rolling moment, S the cross-sectional surface area, q the kinetic pressure, and d the PROJECTILE diameter; SPIN dampening moment coefficient— $C_{\ell\phi} = \partial C_{\ell} / [\partial(\phi d / 2v)]$, where ϕ is the projectile spin rate, v the projectile velocity; overturning PITCH moment coefficient— $C_{m\phi} = \mathcal{M} / q S d$, where $\mathcal{M}$ is the overturning moment; Magnus moment coefficient slope— $C_{m\phi\beta} = \partial^2 C_{m\phi} / [\partial(\phi d / 2v) \partial \beta]$, where β is the ANGLE of sideslip; pitch DAMPING moment coefficient— $C_{mq} = \partial C_{m\phi} / [\partial(Q d / 2v)]$, where Q represents the overturning moment/pitch moment. In all cases the moment aspect refers to aspects of the MOMENT OF INERTIA and the MOMENT ARM (see Figure M.128).

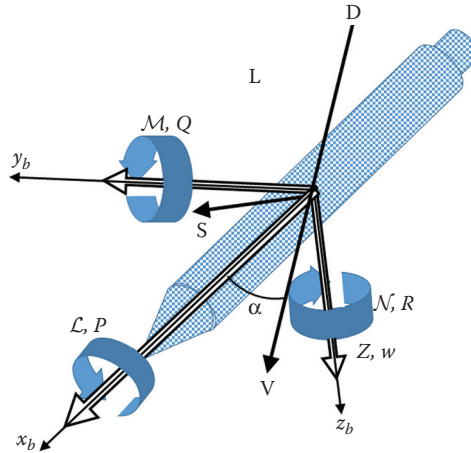


Figure M.128 The concept of moment coefficient illustrated.

Moment of a force

[general] See TORQUE.

Moment of inertia (I_m)

[general, mechanics] Scalar quantity that provides a mechanism to describe the rotational MOTION response of a system of particles with nonuniform or uniform distribution in a geometric shape as the consequence of an external force with respect to a particular axis of rotation. The moment of inertia is defined as $I_m = \sum_i r_i^2 m_i$, in a reference frame of choice as summarized over all the masses ($\sum_i m_i = M$) (each respective mass (m_i) or finite mass ELEMENT dm) constituent identified by (m_i) as a function of each respective location

(r_i) contributed from a system of particles (regardless of size and structure; including atoms and molecules). In integral form $I_m = \int r^2 dm = \int \rho r^2 dV$, with ρ the local density and V the volume of the constituent at a respective location. In rotational KINEMATICS, the net TORQUE (τ) of all constituents of a revolving object around the axis of rotation is defined with respect to the moment of inertia and the angular acceleration (α) as $\Sigma \tau = I_m \alpha$ as the rotational counterpart to NEWTON'S SECOND LAW (see Figure M.129).

Specific examples of the moment of inertia of certain shapes with uniform density are as follows:

SHAPE	MOMENT-OF-INERTIA	SHAPE DRAWING
Circular annulus with inner radius R_1 and outer radius R_2 revolving around the central axis. With M the mass of the unit.	$I_m = M \frac{R_1^2 + R_2^2}{2}$	
Uniform right cone with maximum radius R_1 and length l revolving around the central axis. With M the mass of the shape.	$I_m = \frac{3}{10} MR^2$	
Uniform thin rod length l revolving around the axis through the center of mass, perpendicular to the central axis of the geometry.	$I_m = \frac{1}{12} M \ell^2$	
Uniform solid cylinder with radius R revolving around the central axis of the geometry.	$I_m = \frac{1}{2} MR^2$	
Uniform solid cylinder with length l and radius R revolving around the axis through the center of mass, perpendicular to the central axis of geometry.	$I_m = \frac{1}{4} MR^2 + \frac{1}{12} M \ell^2$	

Figure M.129 Moment of Inertia.

Moment of inertia (L), spin rate

[general, mechanics] In figure skating, the skater can retract the arms and/or an extended LEG, resulting in an increase in rotational velocity based on CONSERVATION OF ANGULAR MOMENTUM, since I_m is reduced with the diminished lengths of the components. The same principles apply to a merry-go-round, moving to and fro the edge changes the rotational angular velocity (see [Figure M.130](#)).

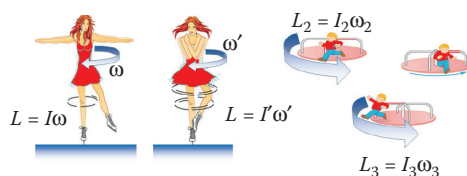


Figure M.130 Spin rate Moment of Inertia.

Momentum ($\vec{p}$)

[mechanics, nuclear] The fact that a body in MOTION tends to stay in motion is captured by the momentum of the body as the MASS (m) multiplied by the velocity (v) expressed as $\vec{p} = m\vec{v}$. More generally, the momentum of a massless entity can be captured as the rate of change (over time: t) in net ENERGY ($E = KE + PE$, where KE is the kinetic energy and PE the potential energy, respectively) as a function of velocity (v), expressed as $\vec{p} = dE/dv$. Under the conditions of NEWTON'S SECOND LAW a body will increase or decrease in momentum directly proportional to the applied net force (F), expressed as $\sum \vec{F} = d\vec{p}/dt$. Analogously, an ISOLATED SYSTEM will have conservation of momentum since no external forces are applied. There is a close relation with impulse, however, momentum generally provides a more useful concept. In PROPULSION with a gas-burning jet ENGINE, the mass of the object will vary (i.e., diminish: Δm), ejecting the propulsion waste with a velocity: $\vec{u}$ yielding the following condition involving the (conservation of) momentum: $d\vec{p}/dt = m(d\vec{v}/dt) - \Delta m(d\vec{v}/dt) + \vec{u}(dm/dt)$; note, there is no external force. (also see ANGULAR MOMENTUM). The product of the mass of a body and its velocity. CGS unit: gm-cm/s (see [Figure M.131](#)).



Figure M.131 The game of croquet illustrating the concept of Momentum, in specific the transfer of momentum.

Momentum change (Δp)

[general] In classical MECHANICS the change of momentum is the impulse: $J = \Delta p$ of a system. The change of momentum with respect to time is force ($F = dp/dt$) resulting from the change in momentum, applied to the phenomenon that made the momentum change; for instance, hitting a nail with a hammer over a short period of contact makes the hammer drive the nail into the wood, or a baseball fly into the outfield (see Figure M.132).



Figure M.132 How the change in momentum provides the force to drive a nail into a piece of wood.

Momentum eigenfunction

[atomic, fluid dynamics] In particle FLUX theory a free particle can be considered to be suspended by a constant potential V , that can be assumed $V = 0V$, which provides the one-dimensional SCHRÖDINGER EQUATION: $-(\hbar/2m)(d^2\Psi/dx^2) = E\Psi$, which yields a WAVE EQUATION solution $\Psi = Ce^{ikx} + De^{-ikx}$, and $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ Planck's constant, and E the particle ENERGY. In order for the PARTICLE to behave with constant momentum this solution is an EIGENVALUE function (i.e., EIGENFUNCTION) of the momentum operator: $p_{x_i} \rightarrow (\hbar/i)(\partial/\partial x_i)$, this will place as boundary conditions: $(\hbar/i)(\partial/\partial x)(Ce^{ikx}) = \hbar k Ce^{ikx}$ and $(\hbar/i)(\partial/\partial x)(De^{-ikx}) = -\hbar k De^{-ikx}$, which represents a particle with momentum $p_x = \hbar k$, with $k = 2\pi/\lambda$ the wavenumber of the eigenfunction with wavelength λ .

Monatomic gases

[general] Gases that consist of single atoms only, examples are all of the noble gases: argon (Ar), helium (He), krypton (Kr), neon (Ne), RADON (Rn), and xenon (Xe).

Mondeville, Henry de (1260–1320)

[biomedical, chemical, optics] (*See* **DE MONDEVILLE, HENRY**.) French physician. The work of De Mondeville is one of the first known documented descriptions of therapeutic applications of light, now known as photodynamic therapy, in the treatment of smallpox.

Monochromatic light

[general, optics] **ELECTROMAGNETIC RADIATION** of a single wavelength, such as produced by a laser. The mechanism of action of the light amplification process in **LASER** produces truly identical photons that are all traveling in **PHASE** (coherent) at one fixed wavelength. Due to **ENERGY** requirements, the production of monochromatic light is complex and cannot be achieved by filtration. Filtering light by spectral means such as a **PRISM** or a colored filter will provide light with a finite bandwidth that relies on the definition of the device used to select a specific wavelength range. Generally, filtering by any means will result in an exponential increase in device cost with decreasing waveband, reaching infinity for a single wavelength.

Monod, Jacques Lucien (1910–1976)

[biomedical, chemical] Biologist from France. Nobel Prize winner in 1965, Physiology or Medicine, with respect to the work on control of enzyme and virus synthesis in collaboration with François Jacob (1920–2013) and André Michel Lwoff (1902–1994), based on the discovery that the adjustment of enzyme concentrations in all biological cells occurs through regulation of transcription; the first step of gene expression, transcribing DNA onto RNA by means of RNA polymerase enzyme (see [Figure M.133](#)).



Figure M.133 Jacques Lucien Monod (1910–1976). (Courtesy of Memorial University of Newfoundland.)

Monod equation

[biomedical, chemical] Mathematical description of microorganism growth rate, described by **JACQUES LUCIEN MONOD** (1910–1976) in 1949. The equation describes the growth of microorganisms based on the maximum specific growth rate ($\mu_{\text{Growth}}^{\text{Max}}$), the concentration of the enzyme substrate that initiates the growth process ($[S_{\text{substrate}}]$), and an empirical “half-velocity” constant defining the conversion process ($K_{\text{conversion}}$, the Monod constant; the concentration of $[S_{\text{substrate}}]$ at “half growth”: $\mu_{\text{Monod}}/\mu_{\text{Growth}}^{\text{Max}}$) as $\mu_{\text{Monod}} = \mu_{\text{Growth}}^{\text{Max}} ([S_{\text{substrate}}] / ([S_{\text{substrate}}] + K_{\text{conversion}}))$.

Monolayer

[fluid dynamics, general, solid-state] Steady-state or FLUID dynamic single uniform one MOLECULE thick film, or layer of closely packed atoms, molecules, or cells at an interface. In FLUID DYNAMICS the monolayer forms a BARRIER between the free FLOW and the rigid or semirigid wall. The WALL may be the surface on the wing of an airplane, or the inner perimeter of a tube or BLOOD vessel. Monolayers can consist of, for instance, but not limited to lipids, nanoparticles, polymers, and proteins. Surfactants will also form a monolayer (e.g., soap). Also known as Langmuir film (see [Figure M.134](#)).

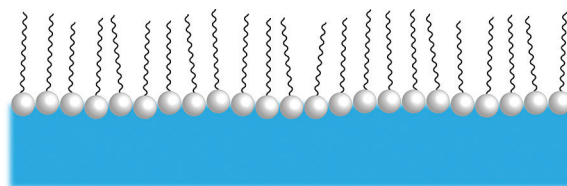


Figure M.134 Illustration of the monolayer concept with regard to soap (detergent/surfactant).

Monolithic

[electronics, general, geophysics] Geological single feature consisting of a stone or rock formation, for instance, a mountain. In semiconductor manufacturing, the monolithic layer is composed of a homogeneous ceramic or composite structure of several nanometer to micrometer thickness, with specific electronic and electromagnetic properties, potentially used to produce light through an excitation process, for instance, in customized LED development.

Monolythic

[electronics, general, geophysics] See MONOLITHIC.

Monomer

[biomedical, chemical] Single molecule. This MOLECULE may bind to other molecules to form a POLYMER, often used in the description of protein structures; e.g., monomeric protein. One example of a common

monomer is glucose, found as a building block in plant MATTER (77%) and related as essential food constituent for human consumption. Glucose form a polymer when bond by glycosidic bonds to form CELLULOSE and starch. Another example is vinyl chloride, which is the monomer that form the synthetic POLYMER POLYVINYL CHLORIDE (PVC) (see [Figure M.135](#)).

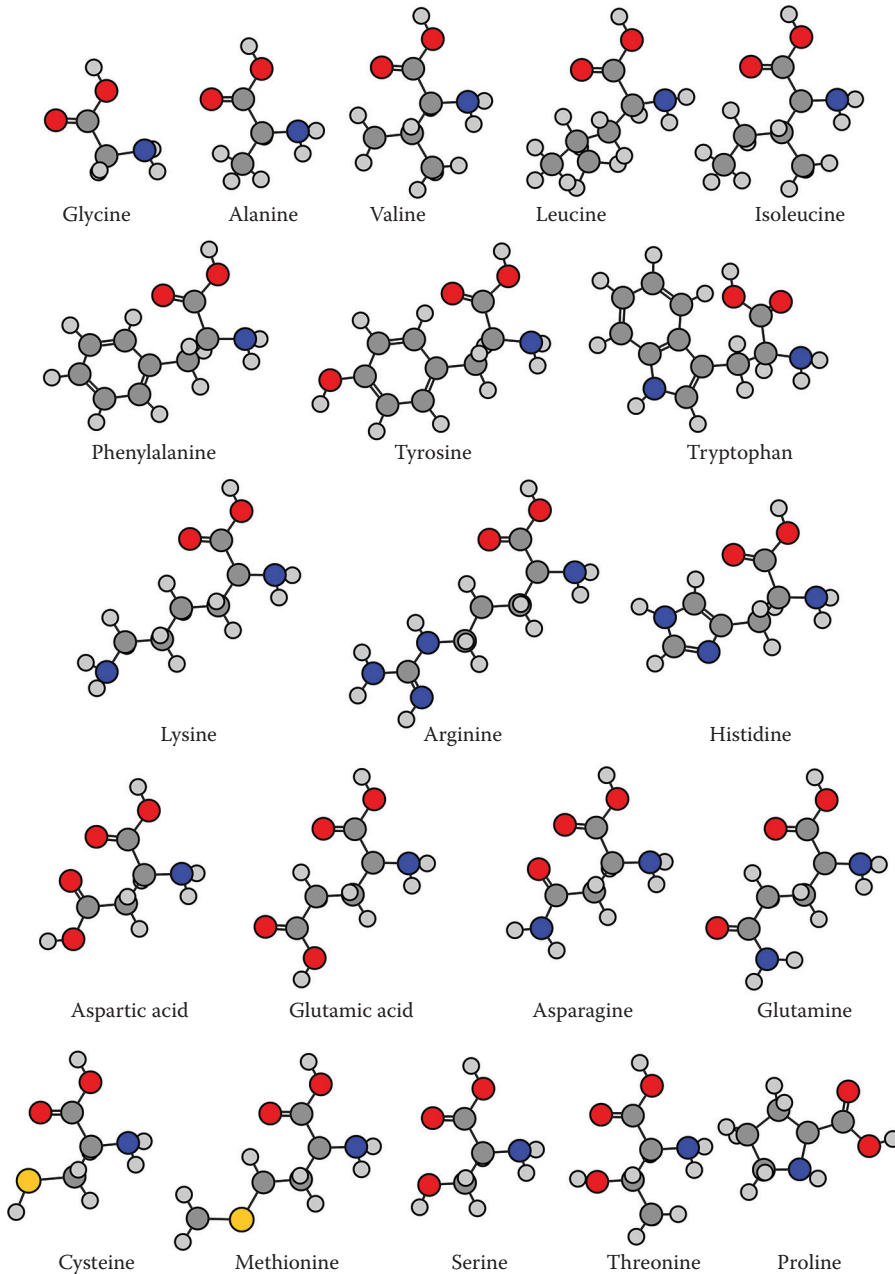


Figure M.135 Structural chemical formulas of 20 basic monomer amino acids.

Monopole, magnetic

[general] Hypothetical particle or magnetic segment within a medium, that consists of only a NORTH or south pole, as such assigned with a “magnetic charge.” In practice this is inconceivable since MAGNETIC FIELD lines are by definition forming a closed loop. The theoretical concept originates from hypothetical concepts such as the GRAND UNIFIED THEORY.

Monopole antenna

[general] Mast ANTENNA that uses GROUND as a MIRROR to produce a virtual bipolar source. The monopole antenna requires half the voltage to produce the same field intensities as a free-space bipolar antenna.

Monte Carlo integration

[computational] Special technique in Monte Carlo methods used for NUMERICAL integration using random numbers based on PROBABILITY of events and associated magnitudes.

Monte Carlo method

[computational] Numerical technique for simulating analog processes based on PROBABILITY distribution of phenomena with certain distributions in MAGNITUDE with the assistance of random number generation to select specific events in the probability distribution on the fly. Monte Carlo simulation allows to account for risks process analysis in quantitative analysis and decision making, providing a range of possible effects and results with the associated probabilities that this will occur as the result of a particular choice of action. The Monte Carlo technique is used in ENERGY estimates and predictions, ENGINEERING, environmental predictions, finance, insurance, manufacturing, project management, research and development, transportation, and the utilities (e.g., oils, GAS) (see [Figure M.136](#)).



Figure M.136 Illustration of the random number distribution used in Monte Carlo modeling, roulette game-of-chance.

Montgolfier, Jacques-Étienne (1745–1799)

[engineering, general] Scientist and inventor from France. Together with his brother JOSEPH-MICHEL MONTGOLFIER (1740–1810) they started the design of the MONTGOLFIER-STYLE HOT-AIR BALLOON, approximately in 1777 (see [Figure M.137](#)).



Figure M.137 Montgolfier brothers, Jacques-Étienne Montgolfier (1745–1799) and Joseph-Michel Montgolfier (1740–1810).

Montgolfier, Joseph-Michel (1740–1810)

[engineering, general] Scientist and inventor from France. Together with his brother JACQUES-ÉTIENNE MONTGOLFIER (1745–1799) they launched the MONTGOLFIER-STYLE HOT-AIR BALLOON, approximately in 1782.

Montgolfier-style hot-air balloon

[engineering, general] Hot-air balloon that served as the basis for the modern hot-air balloon introduced by the two brothers JOSEPH-MICHEL MONTGOLFIER (1740–1810) and JACQUES-ÉTIENNE MONTGOLFIER (1745–1799) from France at first ascent in 1782. The first manned balloon ride was performed in 1783 and subsequently a presentation was made to King Louis XVI of France (1754–1793) and Queen Marie Antoinette Josephina (1755–1793) from Austria (see [Figure M.138](#)).



Figure M.138 Montgolfier hot-air balloon.

Moody diagram

[fluid dynamics] Graphical tool to estimate the FLUID dynamic friction coefficients in FLOW. The derived FRICTION coefficients are also known as MOODY FRICTION FACTOR. The Moody friction factor (found as either λ_{Moody} or f_{Moody}) is a major component in the Darcy–Weisbach major loss equation (see Figure M.139).

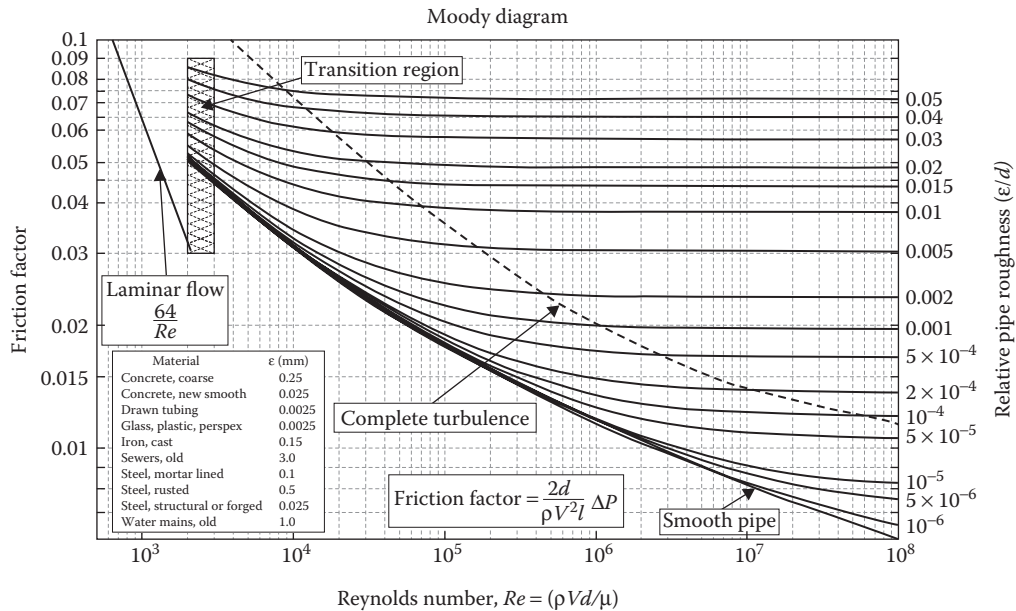


Figure M.139 Moody diagram providing a plot of the Darcy–Weisbach friction factor against Reynolds number for a range of roughness conditions. (Courtesy of S. Beck and R. Collins, University of Sheffield.)

Moody friction factor

[fluid dynamics] Coefficient of FRICTION for FLUID flow, with respect to conduit conditions. The Moody friction coefficient is a complex function of the REYNOLDS NUMBER and relative roughness. Also found as Darcy–Weisbach friction factor.

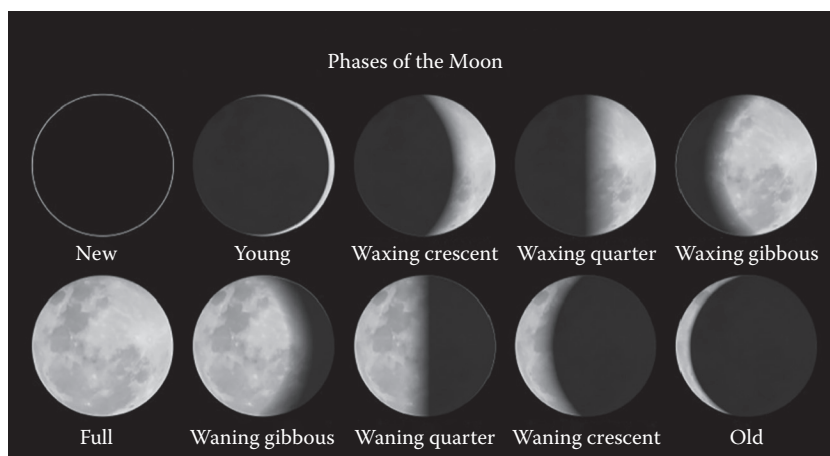
Moon

[astrophysics, general] Celestial body in stable orbit around a larger planetary object. The EARTH has one Moon at an average DISTANCE of 384,400 km (apogee: 405,503 km), with distinct crust, mantle, and core, all with geochemically well-defined compositions and total mass of 7.3477×10^{22} kg. The earth's Moon influence the tidal rise and fall due to gravitational interaction. Certain planets have more than one Moon; for instance, MARS has two moons and JUPITER, NEPTUNE, SATURN, and URANUS each have several moons. Generally moons can also be referred to as (natural) satellites. The earth's Moon has been described in the greatest detail due to its proximity and centuries of observation. Our Moon has several phases of observation; ranging from new Moon to full Moon, with waxing from new to first quarter to full and waning to new, passing the last quarter. The observation of the Moon and its size relative to its position in the sky was described as far back as documented history reveals to the seventh century BC, providing an optical

focusing and magnification by the Earth's ATMOSPHERE when close to the horizon. The Moon ORBITS the Earth in an elliptic plane, approximately in 27.3 days, with respect to the fixed stars, or about Earth 29.5 days, as described by CASSINI's LAWS. The Moon itself has an equatorial rotation velocity of 4.627 m/s, synchronous with the PLANET Earth. Generally, same side of the Moon always faces Earth (the "near side of the Moon"), with the consequent preverbal "dark side of the Moon"; however, this "far side of the Moon" does receive equal proportions of solar exposure (*also see* PHASE OF THE MOON) (see [Figure M.140](#)).



(a)



(b)

Figure M.140 (a) Moon as seen from the northern hemisphere (Courtesy of NASA) and (b) Moon phases in reference to the illumination by the Sun with respect to the position of the Moon to the Sun in the orbit around Earth as well as around the Sun while Earth revolves around the Sun.

Moore, Earle Gordon (1929–)

[computational, general, quantum] An American scientist and the founder and chairman emeritus of the Intel Corporation (a leading manufacturer of MICROPROCESSOR chips for computers, founded in 1968). His work in CHIP design prompted him to coin the statement about the technological increase in computing power, known as MOORE'S LAW, introduced in 1965 (see [Figure M.141](#)).



Figure M.141 Earle Gordon Moore (1929–). (Courtesy of Intel Corporation, Santa Clara, CA.)

Moore's law

[computational, general, quantum] Statement by EARLE GORDON MOORE (1929–) (Intel Corp.) in 1970 relating the technological advancement in MICROPROCESSOR design with respect to the perceived processing speed with 18 month increments of 200%. The alternate interpretation relates the increase of the number of TRANSISTOR components integrated on a processor CHIP in the same manner, double every 18 months to 2 years, which has been reliably appropriate for more than two decades since the first proclamation in 1965. The incremental increase of transistors is directly related to the ever reducing size of electronic hardware. In practicality, the processor power of the computer board is close to double every year at this point.

Morgan–Keenan luminosity classes

[astronomy] Classification of stars by order of luminous radiance: Ib: Supergiants; II: Bright Giants; III: Giants; IV: Subgiants; V: Main-Sequence Stars (*also see* LUMINOSITY FUNCTION *and* HERTZSPRUNG–RUSSELL DIAGRAM) (see [Figure M.142](#)).

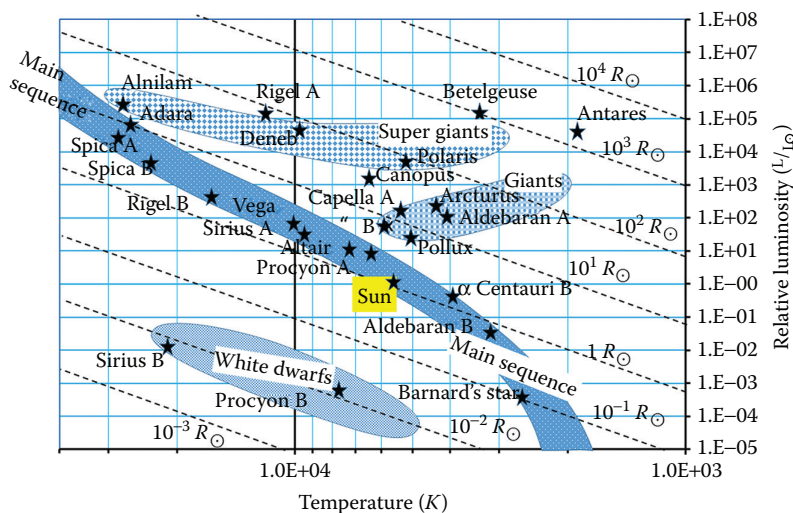


Figure M.142 Diagram of Morgan–Keenan luminosity classes, with the guiding reference: $R_{\odot}$, the radius of our Sun.

M

Morley, Edward Williams (1838–1923)

[general, optics] Scientist, physicist, and chemist as well as theologian, born in the United States. Morley is most known for his work in OPTICS and general PHYSICS as well (*see* MICHELSON–MORLEY EXPERIMENT) (see [Figure M.143](#)).

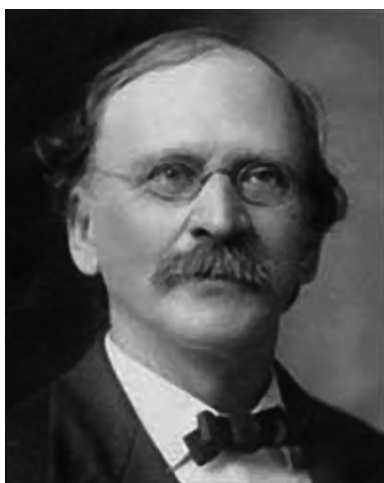


Figure M.143 Edward Williams Morley (1838–1923).

Morse, Harmon Northrop (1848–1920)

[chemical, thermodynamics] Chemist from the United States. Morse introduced refinements to the VAN'T HOFF EQUATION for OSMOTIC PRESSURE under the MORSE EQUATION. Additional work on the pressure effects of solutes was presented by ERNEST STARLING (1866–1927).

Morse, Philip McCord (1903–1985)

[chemical, computational, solid-state] Physicist born in the United States. Philip Morse derived the MORSE POTENTIAL for a harmonic oscillator, specifically applied to the nuclear forces in a diatomic MOLECULE (see [Figure M.144](#)).



Figure M.144 Philip McCord Morse (1903–1985), in 1972. (Courtesy of Massachusetts Institute of Technology [MIT] Web-Museum.)

Morse, Samuel Finley Breese (1791–1872)

[theoretical] Artist and painter from the United States who was also an inventor. In collaboration with the American physicist known for the discovery of self-induction, JOSEPH HENRY (1797–1878), and American mechanical engineer Alfred Vail (1807–1859), the TELEGRAPH system was developed as well as the communication mechanism, referred to as MORSE CODE (see [Figure M.145](#)).



Figure M.145 Samuel Finley Breese Morse (1791–1872) in 1840, photographer potentially Louis Jacques Mandé Daguerre (1787–1851).

Morse code

[theoretical] Pulse pattern of long and short duration pulses that represent letters in the alphabet as well as numbers. Morse code was (and still is) easily transmitted by optical, mechanical, and electronic means over great distances. The coding mechanisms is constructed of combinations of pulses with different duration, referred to as dashes and dots. The duration of a dash is three times the duration of a dot. The principle dates back to approximately 1836, where the collaborative effort of an artist Samuel F. B. Morse, physicist JOSEPH HENRY (1797–1878), and mechanical engineer Alfred Vail (1807–1859) developed an electric TELEGRAPH system. The telegraph system was designed to send electric pulses along wires leading to an ELECTROMAGNET that generated a tapping SOUND under the influence of the electric pulses. Samuel Morse developed a code based the duration and the silence between pulses, to convey messages. The Morse code is resilient against many NOISE factors and can be recognized even under low SIGNAL strength. Morse code only

requires a single wire for transmittance of information. The most well-known Morse code sequence is for S-O-S (save our souls; distress call) (see [Figure M.146](#)).

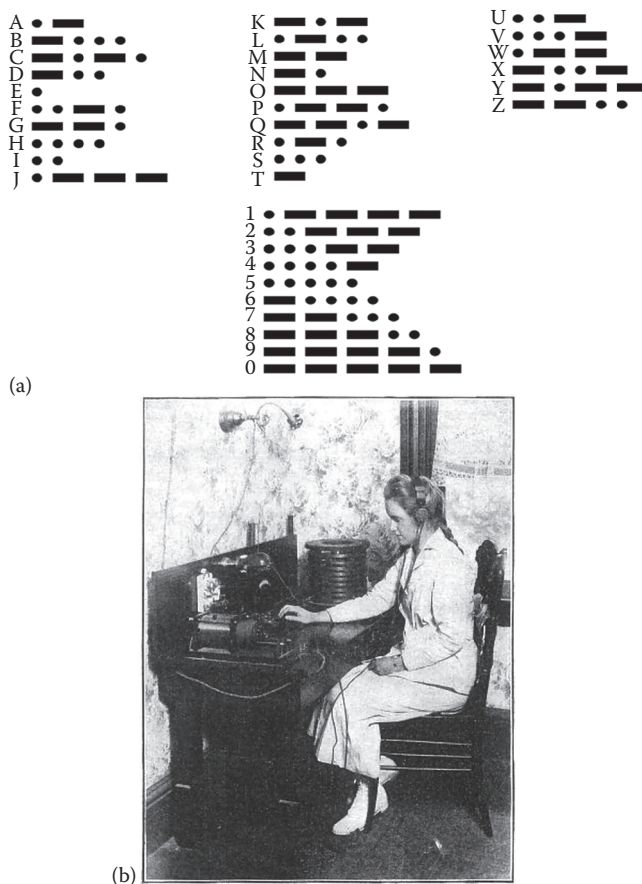


Figure M.146 (a) Morse code encryption scheme and (b) picture of person operating Morse-code apparatus with finger tapping, transmitted via telegraph system and wiring.

Morse equation

[chemical, thermodynamics] COLLOID OSMOTIC PRESSURE (Π) description formulated by HARMON NORTHROP MORSE (1848–1920), expressed as a function of the molarity of the SOLVENT ($[M]$), defined at a specific temperature (T) as $\Pi = i_{vH} [M] RT$, where i_{vH} is the VAN'T HOFF FACTOR (i.e., degree of dissociation: $i_{vH} = 1 + \alpha_{\text{dis}}(n-1)$, where α_{dis} is the fraction of the original molecules of the SOLUTE that have dissociated and n the number of ions/atoms/molecules in the dissociation product), and $R = 8.3144621(75) \text{ J/Kmol}$ the universal GAS constant.

Morse potential

[atomic, chemical, computational, nuclear solid-state, thermodynamics] A simplified diatomic potential expression, constructed from the Rydberg–Klein–Rees (RKR) curves, derived by PHILIP MCCORD MORSE (1903–1985). The Morse potential ($U(r-r_e)$) is expressed as $U(r-r_e) = D_e \left(1 - e^{-\beta(r-r_e)}\right)^2$, where D_e is the dissociation ENERGY (which is the nuclear potential minimum), r_e is the equilibrium DISTANCE between the respective nuclei of the diatomic molecule, and β is a correction factor for the dissociation energy and is related to the REDUCED MASS of the MOLECULE in addition to the resonance frequency harmonics ω_e . The

RESONANCE FREQUENCY of the atomic bond is ruled by a Hook's law type force as $E_\psi = (1/2\pi c)\sqrt{k/\mu_m}(\psi + (1/2)) = \omega_c(\psi + (1/2))$, where E is the energy of VIBRATION, ψ is the vibrational quantum number (integers), k the molecular spring constant, c the speed of light, and μ_m the reduced mass of the molecule with ATOM constituents A and B : $(1/\mu_m = (1/m_A) + (1/m_B))$. The modes of OSCILLATION are as follows: rotation, scissor, translation, and vibration (EXPANSION/contraction). Also known as the potential energy of a diatomic molecule. Equation derived by Philip Morse as a function of the separation between the atoms (r) as $(V(r) = D_{\text{well}}(1 - e^{-a_{\text{well}}(r-r_{\text{eq}})})^2)$, where D_{well} is the well depth, r_{eq} the diatomic equilibrium distance, and $a_{\text{well}} = \sqrt{(k_{\text{well}}/2D_{\text{well}})}$ is the parameter that defines the width of the POTENTIAL WELL, with k_{well} the "spring constant" at the minimum of the well (smaller value of a_{well} corresponds to a larger well) (see Figure M.147).

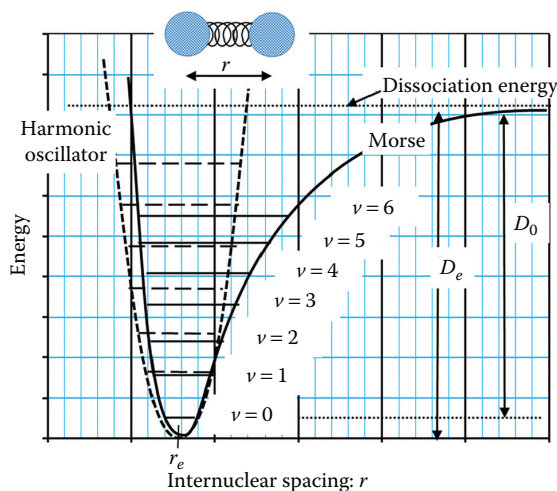


Figure M.147 Graphical representation of the Morse Potential.

Morton number ($Mo_{\text{Liquid}} = g\eta_f^4\Delta\rho/\rho_f^2\sigma^3 = We^3/FrRe^4$)

[computational, fluid dynamics] Dimensionless number that characterizes the size and shape of a droplet or BUBBLE, specifically when used together with the Eötvös number. In this definition we have the following parameters: g the GRAVITATIONAL ACCELERATION, η_f is the FLUID viscosity of the ambient medium, ρ_f the density of the ambient medium, $\Delta\rho$ the difference in DENSITY (ρ) between the LIQUID and GAS PHASE, and σ the SURFACE TENSION coefficient. Additionally, the following DIMENSIONLESS NUMBERS have been inserted: We the Weber number, Fr the Froude number, and Re the REYNOLDS NUMBER.

Moseley, Henry (Harry) Gwyn Jeffreys (1887–1915)

[atomic, nuclear] Physicist from Great Britain. Introducer of the concept of the atomic number in 1915, identifying the quantity of protons in the NUCLEUS of an ATOM, hence indicating the total positive ELECTRIC CHARGE of the nucleus. Moseley performed additional groundbreaking experimental work on X-ray SPECTROSCOPY and implementing BRAGG'S DIFFRACTION law to describe the atomic and crystalline structure of ELEMENTS and their natural occurrence. Bragg's diffraction law was developed by the British father-and-son team SIR WILLIAM HENRY BRAGG (1862–1942) and WILLIAM LAWRENCE BRAGG (1890–1971), for which

they received the Nobel Prize in Physics in 1915. Moseley described the relationship between the ATOMIC NUMBER (Z) and the emission wavelength in X-RAY under CATHODE ray exposure, known as MOSELEY'S LAW (see [Figure M.148](#)).



Figure M.148 Henry (Harry) Gwyn Jeffreys Moseley (1887–1915).

Moseley diagram

[atomic, nuclear] Plot of the square root of the emission frequency of the K and L lines against the atomic number (initially a chosen integer, later connect to the atomic number by Moseley) produces a set of (almost) straight lines resulted. HENRY (HARRY) GWYN JEFFREYS MOSELEY (1887–1915) devised an apparatus for bombarding samples with electrons, of all the ELEMENTS available at the time (early 1900s) ranging from aluminum to gold and measuring the emission wavelengths (in the X-RAY), and hence the frequencies, in the spectra for the respective elements. The diagram allowed for X-ray-based identification of elements. Moseley also “discovered” certain elements that should be in the graph, since there were voids indicating new elements. The square root dependency could be explained by the Bohr theory (see [Figure M.149](#)).

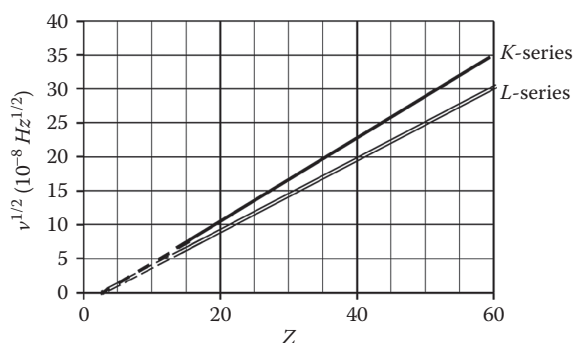


Figure M.149 Moseley diagram with frequency versus proton number (Z ; atomic number). Electrons falling from the K-shell (lowest shell, highest binding energy) produce X-ray radiation known as K-series radiation: K_α , K_β , K_γ respectively, while the second level: L produces an L-series spectrum.

Moseley's law

[atomic, electromagnetism, general, nuclear] Frequency (ν) of the α -line or main K-line (K-ALPHA LINES) in X-RAY emission following the ENERGY pattern described in the BOHR ATOMIC MODEL based on the atomic number Z , designating the number of protons in the NUCLEUS, as developed by HENRY (HARRY) GWYN JEFFREYS MOSELEY (1887–1915) expressed as $\nu = [k_1(Z - k_2)]^2 = 2.476 \times 10^{15} (Z - 1)^2 H\zeta$, where k_1 and k_2 are emission line-dependent constant, which are equal for any $K\alpha$ -line. The value of k_1 changes for the transitions from the L-shell or the M-shell (smaller value for orbits farther out, by order of MAGNITUDE each time). For the K-line $k_1 = (3cR_y/4)^{1/2}$, c the speed of light, $R_y = 1.097 \times 10^7 \text{ m}^{-1}$. The RYDBERG CONSTANT is also known as Moseley's rule.

Mössbauer effect

[nuclear] Special phenomenon in nuclear resonance FLUORESCENCE under conditions of recoil-free GAMMA RAY absorption and emission. The phenomenon was recognized by Rudolf Ludwig Mössbauer (1929–2011) and described in 1958. The collision-free RESONANCE is established by initiating nuclear excitation by means of beta-decay, while simultaneously re-exciting another NUCLEUS of the same species in a resonance scheme, specifically using a collimated beam. Hypothetically, the emitter nucleus and the resonant target nucleus are refrained from movement. This approach relies on the fact that the ENERGY configuration of the process has a line width of $\Gamma^* = \lambda/2\pi\tau_{\text{life}}$, where τ_{life} is the average lifetime of the excited nuclear state and λ the wavelength of the gamma DECAY, with associated (relatively large) interaction CROSS SECTION $\sim (\lambda/2\pi)^2$, and note that the PHOTON carries a momentum: $p = E/c$, where $E = h\nu$ is the photon energy for frequency ν and $c = 2.99792458 \times 10^8 \text{ m/s}$, the speed of light. The realistic manifestation of this principle is emission as a mixture of resonant idealized and unconstrained spectrum. The idealized case has no nuclear motion, which is not easily (not realistic) achieved, while the unconstrained case where there is recoil resulting from the absorption of the QUANTUM momentum (see [Figure M.150](#)).

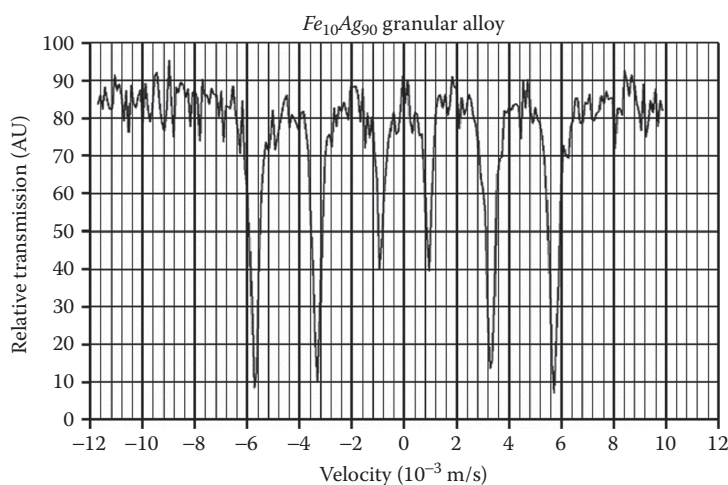


Figure M.150 Mössbauer effect.

Motility

[biomedical, computational, energy, general, mechanics] Capability of moving under the consumption of ENERGY, or having the power to move spontaneously (under a biological fuel system), in particular for unicellular biological life forms, such as spores or sperm. Even though the principle applies to all forms of

life, the specific interests are in the unicellular and simple multicellular organisms. Additionally, motility also refers to the ability of an organism to transport food through the digestive tract. Examples of the food transportation are the PERISTALTIC MOTION of the intestines and esophagus (see [Figure M.151](#)).

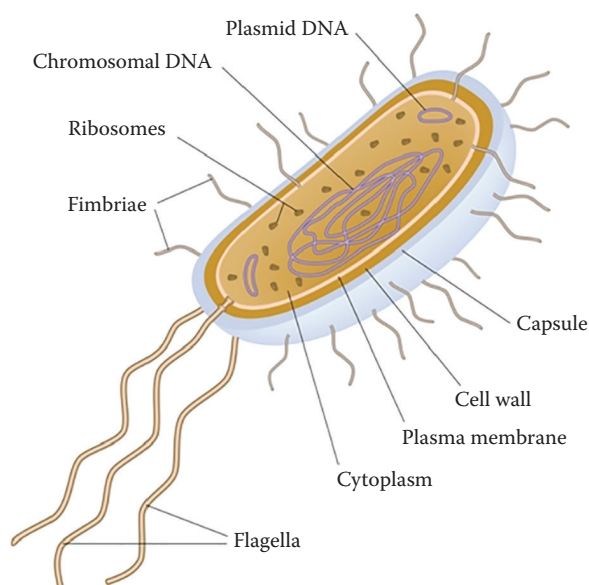


Figure M.151 The motility of a bacterial cell by means of flagella.

Motion

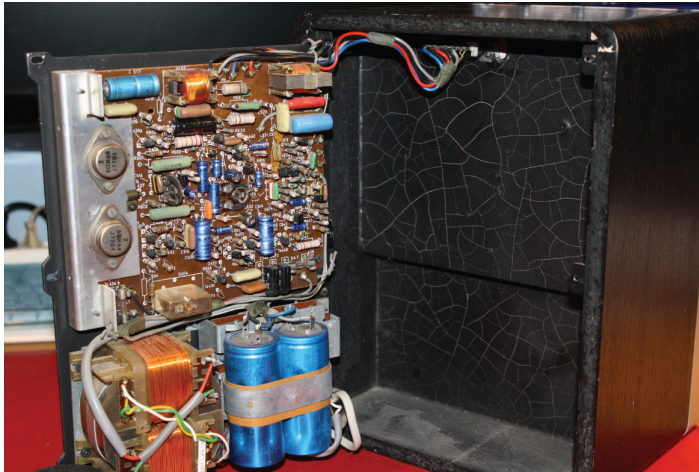
[astrophysics, atomic, biomedical, computational, energy, general, geophysics, mechanics, thermodynamics] Movement of objects in linear displacement, revolution or rotation, or VIBRATION and combinations of these such as PRECESSION. Motion can be split into two topic headings: KINEMATICS and DYNAMICS. Motion around the center of mass becomes rotation, whereas linear free-space MOTION falls under ballistics. Harmonic (vibrational) motion is widely found in many applications (mass-spring concept) as well as in atomic and molecular ENERGY configuration. Motion requires an initial force, or a sustaining force (see [Figure M.152](#)).



Figure M.152 Motion, skateboarded using the muscles in the leg to apply force to the ground to advance the board occupied by the mechanism of motion.

Motional feedback loudspeaker

[acoustics, electronics, fluid dynamics, mechanics] Acoustic emission device with feedback mechanism to modulate the frequency profile and enhance durability. Process developed and implemented in LOUDSPEAKER devices by Philips Electronics, Best, the Netherlands (see [Figure M.153](#)).



(a)



(b)



(c)

Figure M.153 Design and mechanism of operation for the motional feedback loudspeaker. (a) Inside view of feedback electronics within speaker box. (b,c) Piezoelectric pick-up on loudspeaker for feedback mechanism.

Motor

[general] Mechanical device that can perform work and is powered by an ENERGY source. Examples are combustion ENGINE, direct- (DC) and ALTERNATING CURRENT (AC) (electro-) motor, and wind-powered engines. Frequently the class of electromotors is the only group and energy source used to describe motor function. *Electric motors* operate based on any of the following three principles: magnetic, electrostatic, and piezoelectric; which are all physically different in providing the MOTION. The most common mechanism of action is MAGNETIC (see [Figure M.154](#)).

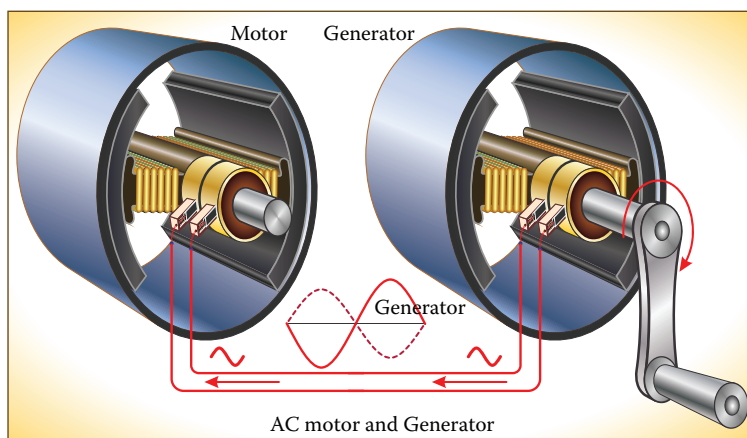


Figure M.154 Electromotor design, in comparison to an electrical generator.

Mott, Nevill Francis, Sir (1905–1996)

[nuclear] Scientist from Great Britain. In 1977, Mott won the Nobel Prize for Physics. Mott investigated the electronic structure of MAGNETIC systems. The special focus of Mott's work was on disordered systems, in particular amorphous SEMICONDUCTORS. Mott shared the Nobel Prize with PHILIP WARREN ANDERSON (1923–) and John Hasbrouck Van Vleck (1899–1980), who worked on similar projects and sometimes collaborated as well (see [Figure M.155](#)).

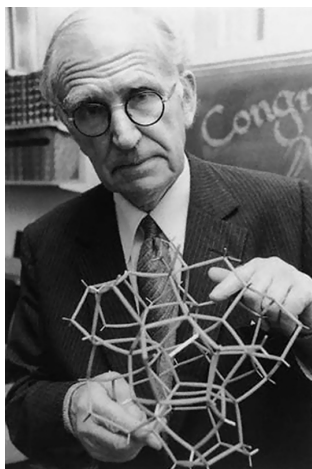


Figure M.155 Sir Nevill Francis Mott (1905–1996).

Moving coil galvanometer

[general] CURRENT (I) measuring device that uses a coil with N windings placed between two permanent magnets with MAGNETIC FIELD B . The torque on the coil as a function of the current passing through the coils will change the direction of a dial as an ANGULAR DISPLACEMENT (θ) attached to the coil as $I = (k/NAB)\theta$, where k is the spring constant that prevents the coil from rotating under the force, applied by a rotating spring with force $F = k\theta r$, where r is the LEVER arm of the attachment of the spring to the coil.

M-phase

[biomedical, energy] The mitotic biological CELL division process which is composed of mitosis and cytokinesis, before the G_1 -phase and after G_2 - and S -phases. M-phase consists of producing two identical cells in a process starting out from one cell starting in the G_1 -phase; also known as the telophase. During mitosis, the organization of the cell becomes physically representative of the final mature cell (G_1 -phase), the chromosomes are recoiling after they have split and reproduced in S -phase. The cell division process is preceded by a nutrient intake episode called the interphase. Cells not in cell division are in a dormant or quiescent stage, also referenced as G_0 -phase. The entropy and internal ENERGY (i.e., Gibbs energy) of the cell changes with the changes in cell division (see Figure M.156).

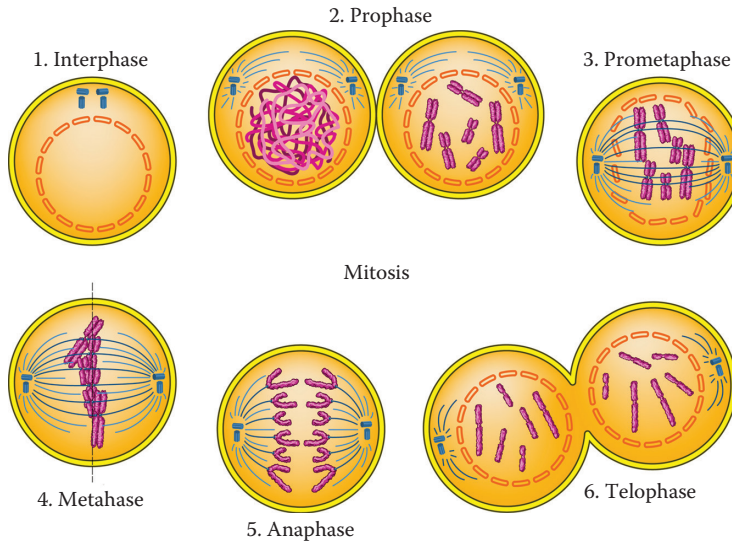


Figure M.156 M-phase in cell mitosis (cell-division), telophase; in the process starting from Prometaphase, into prophase, followed by interphase and metaphase with the anaphase culminating in the telophase.

MRI

[imaging] See MAGNETIC RESONANCE IMAGING.

Mu meson

[nuclear] See MUON.

Multiparameter inversion

[acoustics, computational, geophysics, solid-state] Wave propagation in anisotropic elastic media can be modeled by assuming perturbations to a homogeneous, single format medium, the background model.

Mathematically, the SCATTERING of the propagating waves can be approximated by implementation of a location specific pseudodifferential operator that mimics the discontinuities in the background model. The field perturbations are described by the model vector $\vec{m} = (m_1, \dots, m_n)$, consisting of n material component parameter perturbation fields m_i . The applied field of operators, expressed as a matrix.

$$[N_{\text{opp}}] = \begin{bmatrix} N_{\text{opp}}^{11} & \dots & N_{\text{opp}}^{1n} \\ \vdots & \ddots & \vdots \\ N_{\text{opp}}^{n1} & \dots & N_{\text{opp}}^{nn} \end{bmatrix}$$

yields: $[N_{\text{opp}}] \vec{m} = \vec{m}_{\text{mig}}$. The resulting migration output vector: $\vec{m}_{\text{mig}}$ contains “images” of the WAVE due to perturbations. The observed data (d_{obs}) are linked to a migration operator ($[F_{\text{opp}}]$) as $[F_{\text{opp}}] \vec{m} \approx \vec{d}_{\text{obs}}$, where $[F_{\text{opp}}][F_{\text{opp}}]^* \vec{m} = [F_{\text{opp}}]^* \vec{d}_{\text{obs}}$, with $[F_{\text{opp}}]^*$ the transposed (adjoint) matrix of $[F_{\text{opp}}]$.

Multiple linear regression

[computational] The multiple regression forms an EXPANSION to modeling the relationship between a single or functional variable: x (i.e., explanatory variable) to a SCALAR dependent variable y to include two or more explanatory variables, yielding a three-dimensional relationship.

Multiple photon photoelectric effect

[general] Multiphoton interaction can yield the sum of the ENERGY of the interacting photons, thus acting as if a shorter wavelength single PHOTON created the interaction. The PHOTOELECTRIC EFFECT is generally more effective with higher efficiency at shorter wavelength ELECTROMAGNETIC RADIATION. The multiphoton effect can be achieved under high-power density irradiation, increasing the PROBABILITY of simultaneous photon interaction on an atomic or molecular level.

Multiplication factor

[atomic, nuclear] In the general operations of a nuclear reaction, the reaction will need to be self-sustaining, which involves causing on an average more than one nuclear reactions. The multiplication factor, ν_{neutron} , is the average number of neutrons generated by one FISSION that will initiate another fission, the effective NEUTRON multiplication factor. It is also known as neutron multiplication factor. For $\nu_{\text{neutron}} < 1$, the REACTOR will not sustain a CHAIN REACTION, and is considered subcritical; whereas for $\nu_{\text{neutron}} > 1$ the reactor can go beyond the point of control by the controller bars and moderator bars and is generally considered supercritical (*also see MODERATOR BAR*).

Multiplicity of spectra

[atomic, nuclear, quantum] The multiplicity of spectral lines ($\mathcal{M}_{\text{spectral}}$) for atomic spectral analysis is based on quantum PHYSICS principles on atomic or molecular level. The phenomena of multiplicity of spectral lines applies both to OPTICS and magnetic resonance imaging (MRI). Optically, the principles rely on atomic excitation, specifically the SPIN orientation of the transitions: $\mathcal{M}_{\text{spectral}} = 2\Sigma + 1$, where Σ is the sum of all the spins s and is consistently the number of VALENCE electrons for specific ELEMENTS plus 1, such as POTASSIUM (K), calcium (Ca), scandium (Sc), and vanadium (V). For calcium, this provides an EMISSION SPECTRUM of singles and triplets due to the valence of 2. In NUCLEAR MAGNETIC RESONANCE (NMR) imaging, the same multiplicity applies to the PROTON resonance spectral lines, providing singlet, DOUBLET, triplet, quartet, and so on RESONANCE frequencies. In this case the spectra of a given NUCLEUS follows from spin coupling, specifically coupling to Σ number of equivalent nuclei. In the latter case, the coupling to equivalent nuclei raises the concept of equivalent ligands and uses Pascal's triangle to form the splitting pattern. For instance, 1,1,2-tribromoethane

($\text{C}_2\text{H}_3\text{Br}_3$) has two identical hydrogen nuclei, with concomitant two NMR peaks, one with multiplicity three ($\Sigma = 2 + 1 = 3$, i.e., three resonant lines— H_3 —the peak has three lines; from the Pascal's triangle, it is a triplet), and one with multiplicity two (2; since H_1 and H_2 act equivalently) (see [Figure M.157](#)).

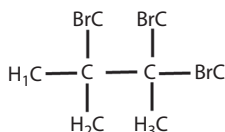


Figure M.157 Molecular bond configuration in 1,1,2-tribromoethane ($\text{C}_2\text{H}_3\text{Br}_3$) that can provide the mechanism to support Multiplicity of Spectra due to the ambivalence of the energy structure.

Multiplier tube

[atomic, nuclear, optics] See **PHOTON MULTIPLIER TUBE**.

Multipole

[computational, electromagnetism, solid-state, thermodynamics] Model of a symmetric periodic system by the sum of sines and cosines in the form of a **FOURIER SERIES** with the necessary parameters (the multipole moments) or as a set of Legendre polynomials in a spherical coordinate system. One example of the use of multipoles in approximations is applied to predicting the electric potential field due to a complex molecule by eliminating the contributions of all the respective atoms (which can become an elaborate task, specifically including the interatomic fields) and decomposing the molecule in a few multipole moments as a reasonable approximation. Examples are monopole, **DIPOLE**, quadrupole, octupole, and so on. Multipoles can provide an acceptable impression of how the field behaves, without the need to know the exact fundamental field.

Multipole moment

[nuclear] The collection of necessary parameters to define the coefficients in the **FOURIER SERIES** and the Legendre polynomials for the description of multipoles.

Multipole radiation

[computational, nuclear] Description of electromagnetic or gravitational radiation resulting from perturbations in the distribution of sources in a time-dependent system. This theoretical mechanisms can describe phenomena ranging from **GRAVITATIONAL WAVES** to gamma radiation due to nuclear **DECAY**.

Muon

[astronomy/astrophysics, atomic, general, nuclear, quantum, thermodynamics] Elementary **MESON** particle in the category of **LEPTON**, unstable but behave very similar to electrons, although with much greater mass. The muon, discovered in 1938, has a mass-equivalent **ENERGY** of $E = mc^2 = 106 \text{ MeV}$. The discovery of the muon

resulted from studying COSMIC RAYS. Generally, two types of muons can be recognized, with opposite charge, each decaying according to a specific path, into ELECTRON (e^-) or POSITRON (e^+) according to their nature, and two neutrinos according to the following rules: $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$ or $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$, where ν_e and ν_μ are neutrinos and anti-neutrinos ($\bar{\nu}_\mu$; $\bar{\nu}_e$), respectively, the lifetime of a muon is approximately 2 μ s (see Figure M.158).

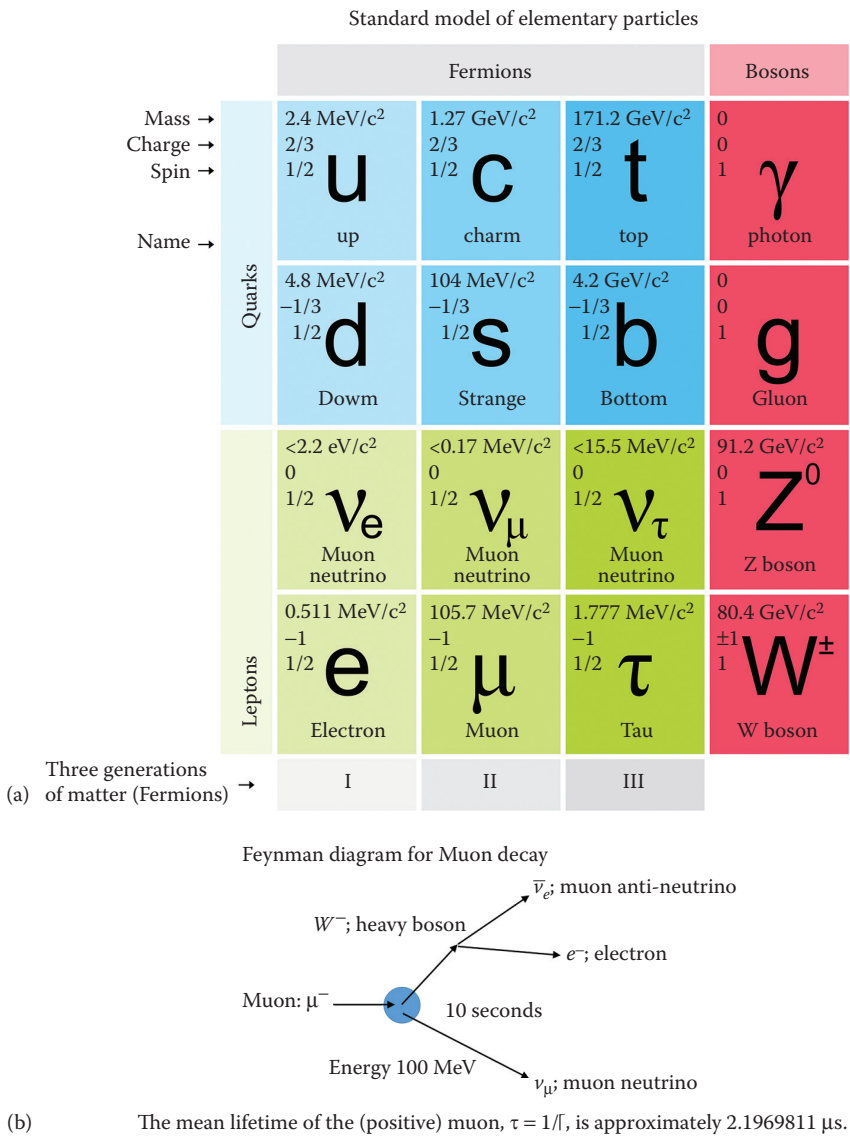


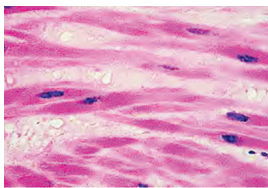
Figure M.158 (a) Placing the muon in the scheme of elementary particles and (b) muon decay mechanism.

Murray's law

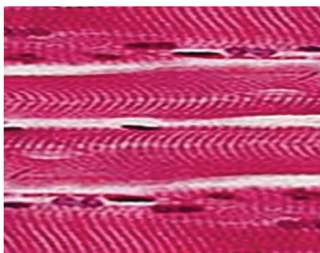
[biomedical, fluid dynamics] In hemodynamic flow there should be certain design constraints that provide conditions to ensure minimization of ENERGY requirements to maintain fluid transport. In BLOOD CIRCULATION the work performed is dependent on, but not limited to, the HEART muscle contraction, vascular COMPLIANCE as well as Bernoulli pressure gradients. Specifically with respect to vascular radius, there is an optimum in the work performed (minimal), balancing work, and momentum (p). The momentum is linked to the FLOW with (average) velocity (v or rather v_{avg} across the vessel diameter) as $p = mv \sim [d(m\dot{x})/dt]$, where the MASS (m) of liquid in a segment of vessel with radius (r) and cross-sectional area (A_{cross}) is changing over time based on the vascular compliance: $\dot{m} = dm/dt = \rho_{\text{fluid}} v_{\text{avg}} A_{\text{cross}}$ where blood is an INCOMPRESSIBLE FLUID and hence the density: $\rho_{\text{fluid}} = \text{const}$. The minimum work associated with flow is defined by Murray's law as the vascular radius for which the following hold true: $dW_{\text{tot}}/dr = 0$, where the total power exerted by the circulation $W_{\text{tot}} = W_{\text{flow}} + W_{\text{blood}}$ is the sum of the power to maintain flow W_{flow} and the effort involved in maintaining blood supply: W_{blood} . The blood flow obeys the POISEUILLE'S LAW: $W_{\text{flow}} = Q\Delta P = 8\ell Q^2 \eta_{\text{visc}} / \pi r^2$, where Q is the flow, ΔP the pressure gradient of length ℓ for a FLUID with VISCOSITY η_{visc} . The "creation of blood" relies on the synthesis of proteins and additional biological processes, which can be captured by the ARRHENIUS EQUATION: $W_{\text{blood}} = \alpha_{\text{blood}} \nabla_{\text{blood}}$, with α_{blood} the production energy for one unit of blood, and $\nabla_{\text{blood}} = \pi r^2 \ell$ the volume of blood.

Muscle

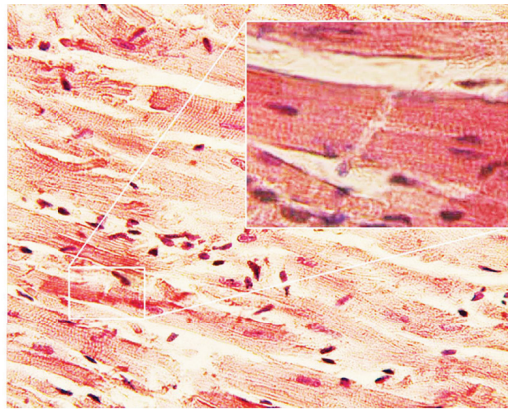
[biomedical, chemical, electromagnetism, mechanics] Mechanical MOTOR function of biological units. In humans three different kinds of muscle can be distinguished: cardiac (in the HEART), skeletal (attached to JOINTS and bone), and smooth (e.g., in the WALL of veins [multiunit] and in the reproductive system as well as the digestive system [visceral]). SKELETAL MUSCLE is connected to bone through cartilage, with seamless integration between the various biological components; the tendon integration with muscle is achieved by aponeuroses (broad fibrous sheets). Muscular contraction is a digital phenomenon. Higher frequency of pulses sent by the motor unit to the muscle increases the contraction. The motor unit itself is stimulated by the brain or through autonomic regulation. This means that the motor unit may act independently, irrespective of will power (see [Figure M.159](#)).



Smooth muscle



Skeletal muscle



Cardiac muscle

Figure M.159 (a). Types of muscles: from left to right represented by histological view: smooth, skeletal, and cardiac (Courtesy Dr. S. Girod, Anton Becker.) and (b) diagram of a motor unit.

Muscle, anatomy

[biomedical, chemical, electromagnetism, mechanics] A **SKELETAL MUSCLE** fiber is a thin elongated cylinder with rounded ends and may extend the full length of the muscle. Beneath its sarcolemma (**CELL MEMBRANE**), the cytoplasm or sarcoplasm of the fiber contains many small, oval nuclei and mitochondria. Within the sarcoplasm are numerous threadlike myofibrils that lie parallel to one another. They play an important role in muscle contractions. The myofibrils contain two kinds of protein filaments: (1) thick ones composed of the protein **MYOSIN** and (2) thin ones composed of the protein **ACTIN**. The arrangement of these filaments in repeated units are called sarcomeres, which produce the characteristic alternating light and dark striations of muscles. Light areas are the I-bands and the darker areas are A-bands. Z-lines are where adjacent sarcomeres come together and thin myofilaments of adjacent sarcomeres overlap slightly. Thus, a **SARCOMERE** can be defined as the area between Z-lines. Myosin filaments are located primarily within the dark portions of the sarcomeres, while actin filaments occur in the light areas. Within the cytoplasm of a muscle fiber is a network of membranous channels that surround each myofibril and runs parallel to it, which is the sarcoplasmic reticulum. Transverse tubules (t-tubules) extend inward from the fiber's membrane. They contain extracellular **FLUID** and have closed ends that terminate within the light areas. Each t-tubule contacts specialized enlarged portions (cisternae) of the sarcoplasmic reticulum near the region where the actin and myosin filaments overlap. These parts function in activating the muscle contraction mechanism when the fiber is stimulated. Each skeletal muscle fiber is connected to a fiber from a nerve cell. Such a nerve fiber is a branch of a **MOTOR** neuron that extends outward from the brain or spinal cord. The site where the nerve fiber and muscle fiber meet is called a neuromuscular junction (myoneural junction). At this junction the muscle fiber membrane is specialized to form a motor end plate. The end of the motor nerve fiber is branched, and the ends of these branches project into recesses (synaptic clefts) of the muscle fiber membrane. The cytoplasm at the ends of the nerve fibers is rich in **MITOCHONDRIA** and contains many tiny (synaptic) vesicles that store chemicals called **NEUROTRANSMITTERS**. When a nerve impulse traveling from the brain or spinal cord reaches the end of a motor nerve fiber, some of the vesicles release neurotransmitter into the gap between the nerve and the motor end plate. This action stimulates the muscle fiber to contract. A muscle fiber contraction is a complex action involving a number of cell parts and chemical substances. The final result is a sliding movement within the myofibrils in which the filaments of actin and myosin merge. When this happens, the muscle fiber is shortened, and it pulls on its attachments. The length and tension of muscles vary indirectly. In the contraction mechanism, the chemical mechanism of action involves kinesins and dyneins, which are microtubule-dependent motor proteins that advance in incremental steps toward opposite ends of the microtubule cables. Both mechanochemical enzymes make use of a pair of motor domains that take intersecting hand-over-hand advances along the surface of the microtubule. In vitro measurements have provided proof that these head domains make steps of 8 nm and generate in the order of 6 pN of peak force during a single ATP hydrolysis cycle. Chemical advancement velocities are ATP dependent of single kinesin molecules obey the Michaelis–Menten relationship. Myosins are one- and two-headed actin-dependent chemical motors with step sizes ranging from 5 nm to greater than 40 nm. In particular, the two-headed isoform of Myosin II contribute in the contractile assemblies that manipulate the sarcomere length in muscle cells as well as influence the actomyosin ring constriction as part of the cytokinesis during cell division. Because the orientation of these actin filaments have inherently different polarity, myosins reverse polarity along the myosin filaments, and ATP hydrolysis cause the actin filaments to advance toward each other as an integral part of the motor domains. One-headed myosins do not have tails that form coiled coils, in contrast to Myosin I. One-headed myosins as a result do not actively participate in contractile mechanisms. Alternatively, the tails of these myosins facilitate the binding of vesicles and organelles and in this manner to transport them in lengthwise direction along actin filaments (see [Figure M.160](#)).

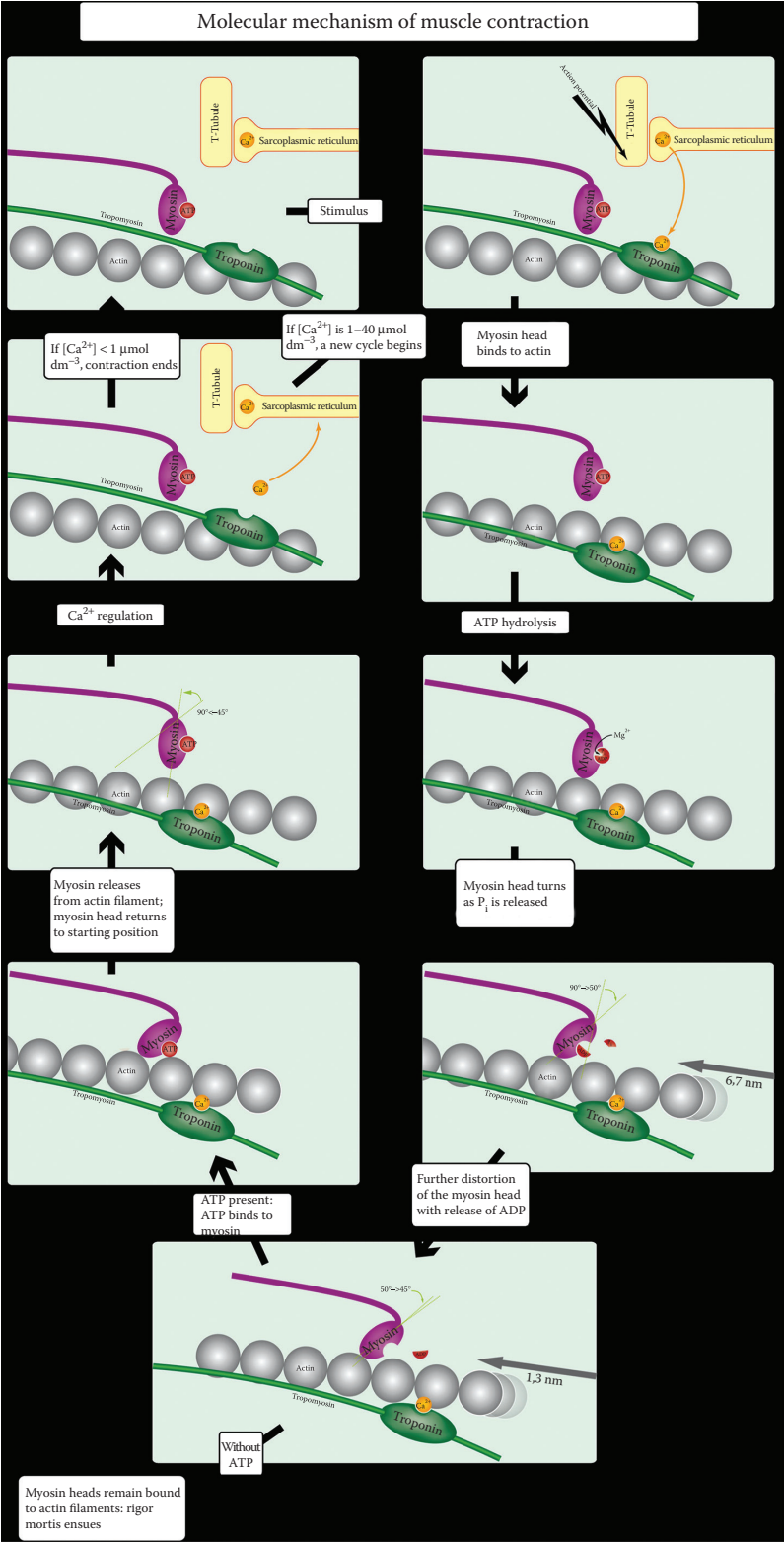


Figure M.160 Muscle fiber anatomical diagram. Muscle contraction based on the chemical attraction between actin and myosin fibers. (Courtesy Hank van Helvete.)

Muscle, major skeletal groups

[biomedical, chemical, electromagnetism, mechanics] The major SKELETAL MUSCLE groups are facial, mastication, head, pectoral girdle, arms, abdominal, pelvic, and legs. The anterior view of skeletal muscles within the HUMAN BODY shows the frontal muscle structure. The facial muscles are epicranii, orbicularis oculi, orbicularis oris, buccinator, zygomaticus, and platysma. The epicranii covers the upper part of the cranium and has two parts, one that lies over the frontal bone and another that lies over the occipital bone. Lifting the eyebrows and making the forehead wrinkle are its main functions. Multiple stimulations of these muscles can lead to headaches. The orbicularis oculi is a ring of muscle that surrounds the EYE and is used for closing or blinking of the EYE. It also aids in the FLOW of tears. The orbicularis oris orbits the mouth and is also known as the kissing muscle since it allows the mouth to pucker and help keeping food in place is done by the buccinator muscles. They also aid in blowing AIR out of the mouth. Zygomaticus' main function is allowing the corner of the mouth to smile or laugh. The platysma extends from the chest to the neck and its function can be seen by the expression of pouting. Chewing movements are accomplished by four pairs of muscles that are part of mastication. These muscle pairs are masseter, temporalis, medial pterygoid, and lateral pterygoid. Two of these pairs close the mouth while the others allow for side-to-side movements. The masseter is primarily for raising the jaw. A fan-shaped muscle used also for raising the jaw is known as the temporalis. The medial pterygoid is used for closing the jaw and allowing for the sliding movements. The lateral pterygoid allows the jaw to close and move forward. There are four pairs of muscles that move the head, allowing for rotation. The sternocleidomastoid is located in the side of the neck and when one side contracts, the head is turned to the opposite side. When both are contracted, the head is bent toward the chest. In the back of the neck, the splenius capitis allows the head to rotate and bend toward one side. For rotating, extending, and bending the head, the semispinalis capitis and longissimus capitis both help with these functions. Muscles that move the pectoral girdle or chest area include the trapezius, rhomboideus major, levator scapulae, serratus anterior, and pectoralis minor. The trapezius muscle raises the shoulders allowing for the "shrugging" expression. The rhomboideus major connects the upper thoracic vertebrae to the scapula and helps to raise the scapula. The levator scapulae runs almost vertical along the neck also helping to raise the scapula. Moving the scapula downward is accomplished with the serratus anterior. It also moves the shoulders forward when pushing something. The pectoralis minor lies beneath the pectoralis major and can move the ribs. For the upper arm, the muscles can be grouped by their primary actions of flexors, extensors, abductors, and rotators. The flexors are the coracobrachialis and pectoralis major, which flex the arm and move the arm across the chest. The extensors are the teres major and the latissimus dorsi that allow for rotation and moving the shoulder down and back. The supraspinatus and deltoid both help in abduction in the upper arm. The subscapularis, infraspinatus, and teres minor allow for rotation medially and laterally. In the forearm there are seven major muscles and can be categorized by their action. The flexor muscles are the biceps brachii, brachialis, and the brachioradialis all of which help in the rotation and lateral movements about the elbow. The primary extensor of the elbow is the triceps brachii. To rotate the arm, the supinator, pronator teres, and pronator quadratus allow for movements. In the wrist, hand, and fingers, the two major groups are flexors and extensors. Flexing of the wrist is accomplished with the assistance of the flexor carpi radialis and the flexor carpi ulnaris. The palmaris longus connects the humerus to the palm and functions to flex the wrist. To make a fist the flexor digitorum profundus flexes the distal JOINTS of the fingers. All four of these are flexors. The extensors of the wrist and hand are the extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, and the extensor digitorum. The first three aid in extending the wrist while the last one deals with the functions of the fingers. Four muscles located in the abdominal WALL region help with breathing, defecation, urination, and childbirth. These muscles are the external oblique, internal oblique, transversus abdominis, and the rectus abdominis. All of these muscles function in a similar manner and compress the abdominal cavity. The pelvis region consists of two major muscle sheets that are the pelvic diaphragm and the urogenital diaphragm. The pelvic diaphragm has two major muscles that are the levator ani and the coccygeus that provide a sphincter-like action in the anal canal and the vagina in women. The three major muscles within the urogenital diaphragm are the superficial transversus perinei, bulbospongiosus, and the ischiocavernosus muscles. The superficial transversus perinei supports the pelvis. The other two help in urination within men

and constriction of the vagina from opening in women. In the thigh, there are two groups: the anterior and posterior groups. The anterior groups' main job is for flexing while the posterior groups are for extending or rotation. The psoas major and the iliacus make up the anterior group and their function is to flex the thighs. The posterior group consists of the gluteus maximus, gluteus medius, gluteus minimus, and the TENSOR fasciae latae. These muscles help in flexing and rotating the thigh. A third group of muscles, the adductor longus, adductor magnus, and gracilis, adduct, flexes and/or rotates the thigh. The muscles of the LEG can be separated into two categories that are the flexors and extensors about the knee. The flexors are the biceps femoris, semitendinosus, semimembranosus, and sartorius and all help to flex and rotate the leg. The extensors of the lower legs are the quadriceps femoris, which extends the leg at the knee. In the ankles, feet, and toes, there are four categories of muscles based on their function. The dorsal flexors, which include the tibialis anterior, peroneus tertius, and extensor digitorum longus aid in the moving the foot upward. The plantar flexors move the foot downward and contain the GASTROCNEMIUS, soleus, and flexor digitorum longus muscles. Turning the sole of the foot outward or inward is accomplished by the two groups: the invertor and evertor. The tibialis posterior is within the invertor group and allows for the INVERSION of the foot. The eversion of the foot is done by the peroneus longus that is within the evertor group. Although each muscle is specialized within a certain area, all of these muscles help in maintaining posture and movement (see Figure M.161).

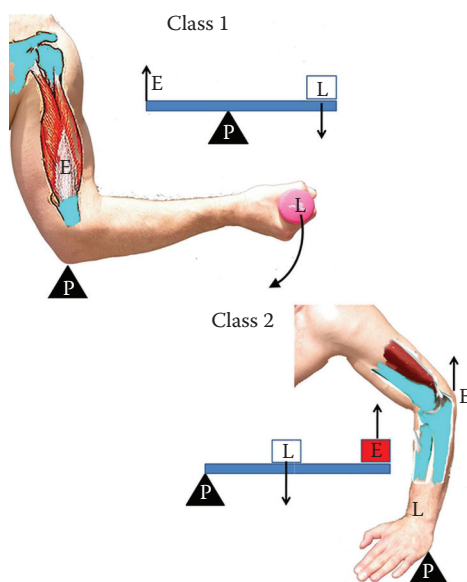


Figure M.161 Diagram of lever classes, with respective locations of movement force, resistance, and axis of rotation defining the individual classes. (Continued)

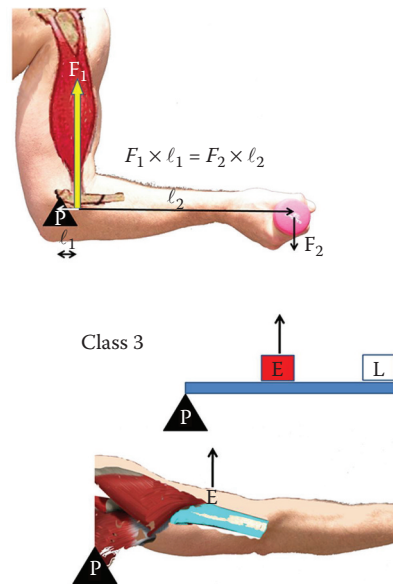


Figure M.161 (Continued) Diagram of lever classes, with respective locations of movement force, resistance, and axis of rotation defining the individual classes.

Muscle, performance

[biomedical, chemical, electromagnetism, mechanics] The following factors affecting SKELETAL MUSCLE strength and performance can be identified. Gender, AGE, training experience, muscle strength, and fatigue all affect strength performance. Muscles in humans makes up 40%–43% of the total body weight in men on world-wide average; and respectively, 23%–25% statistically averaged in women. For a healthy, average height woman who weighs 62 kg, 7 kg is composed of bones, 16 kg of organs and SKIN, 16 kg of fat, and 23 kg of muscles. Both male and female can develop muscular strength at the same rate, although due to hormones, namely testosterone, male muscles have a greater potential for strength. As humans mature, strength increases. However, roughly by age 30 (depending on a broad range of boundary conditions, including training and consumption of food, as well as natural and artificial chemicals), muscles start to degenerate. The degeneration is a reversible process but continuous training is required. The length of time devoted to training and the type of training regiment influence muscle strength. The initial length of the muscle fibers and the insertion length affect the amount that muscles can LIFT and support. Fatigue relates to the condition that the muscle does not allow for the same amount of power output. FATIGUE is highly variable and is influenced by the intensity and duration of the contractile ACTIVITY, by whether the muscle fiber is using aerobic or anaerobic METABOLISM, by the composition of the muscle, and by the fitness level of the individual. Most experimental evidence suggests that muscle fatigue arises from excitation–contraction

failure of control neurons and neuromuscular transmission. The ability for muscle to change its length or lengthwise tension has been shown by the process of contraction. The underlying factor is the exchange of energy from the BLOOD stream with the muscle cells (see [Figure M.162](#)).

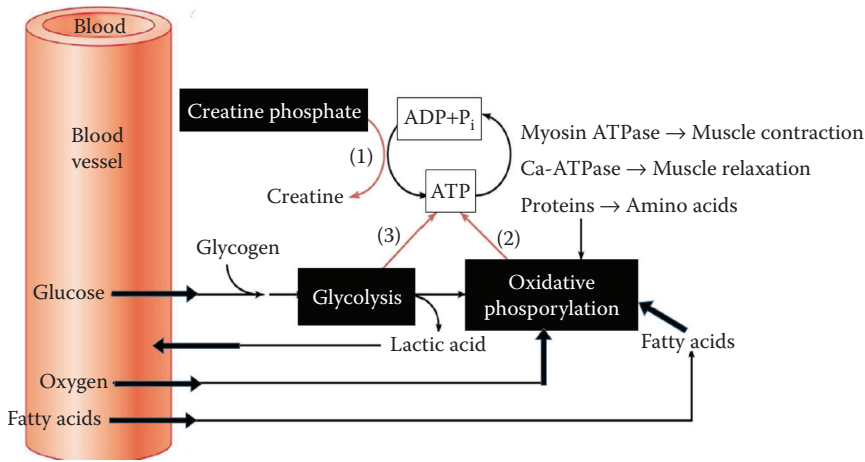


Figure M.162 Diagram of energy exchange with muscle cells to support function. In addition, the production of waste during muscle action is illustrated, eluding the potential build-up of lactic acid, generating muscle fatigue and cramp. The build-up of lactic acid degrades the natural metabolic activities.

Muscle physics, skeletal muscles

M

[biomedical, chemical, electromagnetism, mechanics] A **LEVER** is a simple mechanical machine consisting of a bar on a fixed point that transmits a force. Lever types are defined by three classes according to the axis of rotation, resistive force, and movement force. In a third-class lever, the movement force is applied between the axis of rotation and the resistive force. This lever favors movement speed over movement force. Most muscles in the **HUMAN BODY** use this type of lever. A second-class lever is one in which the **RESISTANCE** is between the movement of force and the axis of rotation. This type allows for great movement force. When the axis of rotation is between the movement force and the resistance this lever is known as a first-class lever. They are like third-class levers since they are big on movement speed and lack in movement force. The bicep **MUSCLE** works as a third-class lever where the movement of force is between the axis of rotation and the resistance. The mathematical relationship of the force can be calculated upon knowing some muscle measurements. People are built differently and depending on their muscle force, force lever, or resistance lever to maintain balance and perform functions. Torque is the force that tends to rotate and turn things. Mathematically, it is equal to the force multiplied by the **DISTANCE**. This distance is usually radial from a central point. Power is the measure of how fast work can be done. It equals the amount of torque on an object multiplied by the rotational speed. To solve power as a function of human output, the following question can be proposed: How much power can a human output? One way to solve this problem is to see how fast one can run up a flight of stairs. First, measure the height of a set of stairs that reaches three stories. Second, record the time to run up the stairs. Finally, divide the height of the stairs by the time, where this equals the instantaneous speed. The weight of the individual must also be known. For instance, if it took 15 s to run up 10 m, then the speed equals 0.66 m/s (only speed in vertical direction is important). Then one needs to figure out how much force was exerted over 10 m, this force is equal to your weight. The amount of power output = weight multiplied by speed. $\text{Power}(W) = [\text{height of stairs(m)}/\text{Time to climb(s)}] * \text{weight}$ (Units: Newton [N]). The contractile strength of a muscle is most closely related to its cross-sectional size. The electrical **ACTIVITY** in muscle is due to the effect of the concentration gradients, the difference in potential across the membrane, and the **ACTIVE TRANSPORT** system. Positive and negative charged ions within the muscle fiber have the ability to move between intercellular fluids. These charges create a differential in potential. The net effect of these charges is a **POSITIVE CHARGE** on the exterior of the **MEMBRANE** and a negative

charge on the interior. In a healthy neuromuscular system, this polarized muscle fiber remains in equilibrium until upset by an external or internal stimulus. There are different measurement techniques to measure the mechanical and electrical properties of muscle. A dynamometer measures the mechanical force or power a muscle can exert and electromyography measures the electrical activity related to muscle contractions. Dynamometers measure mechanical power and come in a variety of different configurations. One such configuration allows measurement of the clench action of hands. The basis of surface myoelectric activity is the relationship between the ACTION POTENTIAL of muscle fibers and the extracellular recording of those action potentials at the SKIN surface. Electrodes, external to the muscle fiber can be used to detect action potentials. The most common electrodes are surface and fine wire electrodes. For general muscle groups surface electrodes are suitable, however, they are limited in detecting small muscles or muscles deep within the body, where fine wire electrodes are recommended. Detection electrodes are usually used in a bipolar manner. Two electrodes are positioned on the muscles while a third is a reference (GROUND) to the body. A difference preamplifier increases the AMPLITUDE of the signals between each of the detecting electrodes and the common mode reference. Signals nearly zero are deemed common mode signals. The difference preamplifier improves the signal-to-noise ratio allowing the SIGNAL of small twitch to be detected. The most common NOISE problem is 60 Hz interference. This signal distortion occurs when the reference ELECTRODE is not applied properly, a loose wire, or when electrical fields persist (see [Figure M.163](#)).

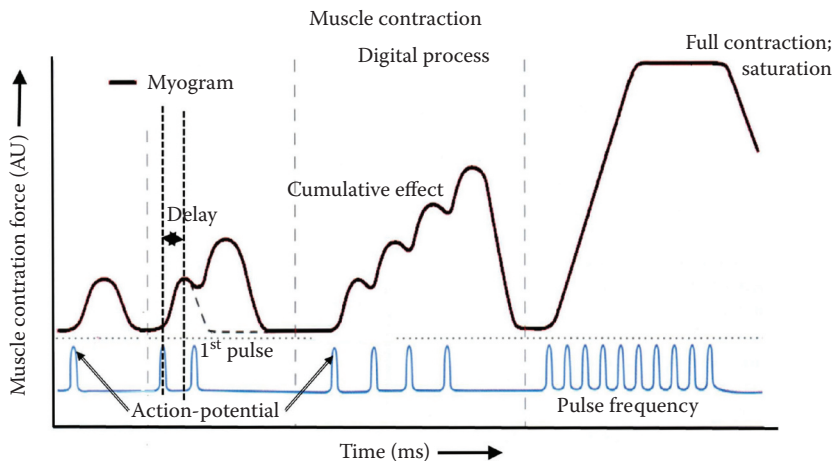


Figure M.163 Binary response of muscle contraction to electrical stimulus pulse trains.

Muscle relaxation

[biomedical] After DEPOLARIZATION the MEMBRANE of the muscle CELL repolarized, at which time the chemical “heads” on both the ACTIN and the MYOSIN of the sarcomeres are losing their attraction, allowing recoil to extend the muscle cell to expand.

Muscles, functioning

[biomedical, chemical, electromagnetism, mechanics] The length and tension of muscles vary indirectly. When a muscle contracts because of a LOAD applying a force, the MUSCLE produces one of two types of contraction: ISOTONIC or ISOMETRIC. Skeletal muscle contracts either by increasing or decreasing force while maintaining the same length (isometric) or shorten through constant force (isotonic). *Note:* Muscles generally have an ANTAGONIST or external phenomenon that increases the length of the muscle. Antagonists are for instance biceps and triceps in the human upper arm, whereas in BLOOD vessels the stretch is achieved by the pressure associated with the blood flow. A SKELETAL MUSCLE fiber is a thin elongated cylinder with rounded ends and may extend the full length of the muscle. Beneath its sarcolemma (CELL MEMBRANE), the cytoplasm or sarcoplasm of the fiber contains many small, oval nuclei and MITOCHONDRIA. Within the

sarcoplasm are numerous threadlike myofibrils that lie parallel to one another. They play an important role in muscle contractions. The response to a single stimulation or ACTION POTENTIAL is called a twitch. A twitch contains three parts: a latent period, a contraction period, and a relaxation period. During the latent period, there is no change in length but the impulse travels along the sarcolemma and down the t-tubules to the sarcoplasmic reticulum. Calcium is released during this period, triggering the muscle to contract. The contraction period is when the tension in the muscle increases causing a swiveling action of the SARCOMERE components. The contraction following from the chemical attraction resulting from the electrical POLARIZATION of both the ACTIN and the MYOSIN can be described as a rate of bond-forming (number of bonds: n_b) process expressed as $dn_b/dt = k_f n_L n_R - k_r n_b$, where k_f is the forward rate constant, n_L the number of ligands involved, and k_r the reverse rate constant. GEORGE IRVINE BELL (1926–2000) defined the rate constant as $k_r = k_{r0} \exp[\gamma_b F / N_c k_B T]$, with F the applied contraction force, N_c the number of LIGAND complexes in the actin–myosin volume, $k_B = 1.3806488 \times 10^{-23} \text{ kgm}^2/\text{s}^2\text{K}$ the Boltzmann constant, γ_b the extension of the muscle defined as the DISTANCE between adjacent attractive molecules (the actin molecules grab sequential molecules on the myosin in each stage of the contraction), k_{r0} the unloaded reverse rate constant in the absence of applied forces, and T the muscle temperature (giving additional meaning to “warming-up”). The molecular ADHESION was defined by Bell as the force per unit chemical bond: $f_b = F/n_b = 0.7(k_B T/\gamma_b) \ln([L]/K_D^0)$, where K_D^0 is the dissociation rate for the unstressed bonds and $[L]$ the free ligand concentration. This ADHESION applied generally to all cellular molecular attractions. The muscle tension decreases during the relaxation period and returns to its original shape. The three components of the twitch and the different types of contraction are well defined. When an increase in frequency with which a muscle is stimulated increases, the strength of contraction also increases known as WAVE summation. This occurs by re-stimulation of muscle fibers while there is still muscle contraction ACTIVITY. With several stimulations in rapid succession, calcium levels in the sarcoplasm increase and produces more activity and a stronger contraction. When rapid stimulation occurs and there is not enough time between successive stimulations a buildup of calcium can occur and there will be no relaxation between stimulations. This leads to a smooth sustained contraction known as tetanus. There are three types of muscle in the HUMAN BODY: skeletal, smooth, and cardiac. Smooth muscles can be found lining organs in the body, and cardiac muscle pertains to the HEART. The movements of the bones at JOINTS and posture maintenance are the main job of skeletal muscle. Skeletal muscles mode of control is voluntary, meaning the user has control of its actions, while smooth and cardiac muscles are involuntary. Smooth muscle is controlled by the autonomic nervous system and is found primarily in the walls of organs and tubes. The spindle-shaped cells that make up the composition of this type of muscle are arranged in sheets. These cells contain small amounts of sarcoplasmic reticulum but lack transverse tubules. The cells are made up of thick and thin myofilaments but do not contain sarcomeres and therefore are not striated like skeletal muscles. Chemically, calcium binds to a protein and induces contraction. There are two types of smooth muscles: visceral and multiunit. Visceral is found in the digestive, urinary, and reproductive systems. For this type of smooth muscle, a unit is composed of multiple fibers that contract and in some cases are self-excitable. In multiunit smooth muscle, nervous stimulation activates motor units. This type is found lining the walls of large blood vessels and in the EYE. They also are located at the base of follicles and can produce a “goose-bump” effect. Cardiac muscles have a distinctly different configuration. Heart walls have three distinct layers, which are the endocardium, myocardium, and epicardium. The endocardium lines the CIRCULATORY SYSTEM, is the innermost layer, and is composed of epithelial tissue. The myocardium is the thickest layer and consists of cardiac muscles. The epicardium is a thin layer and is the external MEMBRANE around the heart. Cardiac muscle is striated and contains sarcomeres, which makes this muscle similar to skeletal. Adjacent cells are joined end-to-end at structures known as intercalated discs. These discs contain two types of junctions: desmosomes and gap junctions. Desmosomes act like rivets and hold cells tightly together while gap junctions allow action potentials to spread from one cell to another. The specific characteristic for the heart muscle is the intercalated discs with desmosomes and gap junctions. Cardiac muscle forms two functional units called the atria and ventricles. There are two of each where by the atrias both act together, followed by the ventricles. For contraction, there are two types of cells: contractile cells and autorhythmic cells. The contractile cells contract when stimulated while the autorhythmic cells are automatic. For focus of discussion of this topic, only skeletal muscle will be explored. Skeletal muscles have

the ability to shorten quickly and recover, where this action is defined as contraction. One end of the muscle, origin, is stationary while its other end, insertion, shifts. A contraction always moves from the insertion to the origin. When a contraction occurs, both the AGONIST muscle and ANTAGONIST muscle work against each other. The agonist muscle or flexion is the muscle that is being acted upon while the antagonist or extension muscle contracts in opposition to the flexion. A contraction is only the shortening of the muscle and does not describe the actual generation of a force. A force only occurs when there is a RESISTANCE to the muscle contraction. To understand the nature of contractions, the ANATOMY of skeletal muscle must be studied. Second, the PHYSIOLOGY of muscular contraction, meaning the excitation and relaxation will be investigated. The PHYSICS of the muscle acting as a lever for skeletal muscle is one ENGINEERING point that shows the impact of the attachment to the bone to provide the level, comparing human arms to that of apes and monkeys. Muscle is composed of several kinds of tissue including striated cells, nerve, blood, and various connective tissues. The basic unit of contraction in an intact skeletal muscle is a motor unit, composed of a group of muscle fibers and a motor neuron that controls them. When the motor neuron fires an action potential, all muscle fibers in the motor unit contract. The number of muscle fibers in a motor unit varies, although all muscle fibers in a single motor unit are the same fiber type. Thus, there are fast-twitch motor units and slow-twitch motor units. The determination of which kind of fibers associated with a particular neuron appears to lie with the NEURON itself. Force of contraction within a skeletal muscle can increase by recruiting additional motor units where by this process is called motor unit recruitment. An individual muscle is separated from adjacent muscles and held into position by layers of fibrous connective tissue called fascia (a bundle). This fascia is part of a network of connective tissues that extends throughout the skeletal muscle system and its attachment with other parts. These connective tissues become either tendons or aponeuroses. The fibers in the tendon become intertwined with bone, which allows muscle to be connected with bone. Aponeuroses are broad fibrous sheets that may be attached to adjacent muscles. The layer that closely surrounds a skeletal muscle is called the epimysium. Other layers of connective tissue called the perimysium extend inward from the epimysium and separate the muscle tissue into small compartments. These compartments contain bundles of skeletal muscle fibers called fascicles. Each muscle fiber within a fascicle is surrounded by a layer of connective tissue in the form of a thin, delicate covering called endomysium. These layers allow for some independent movement as well as allowing blood vessels and nerves to pass through (see Figure M.164).

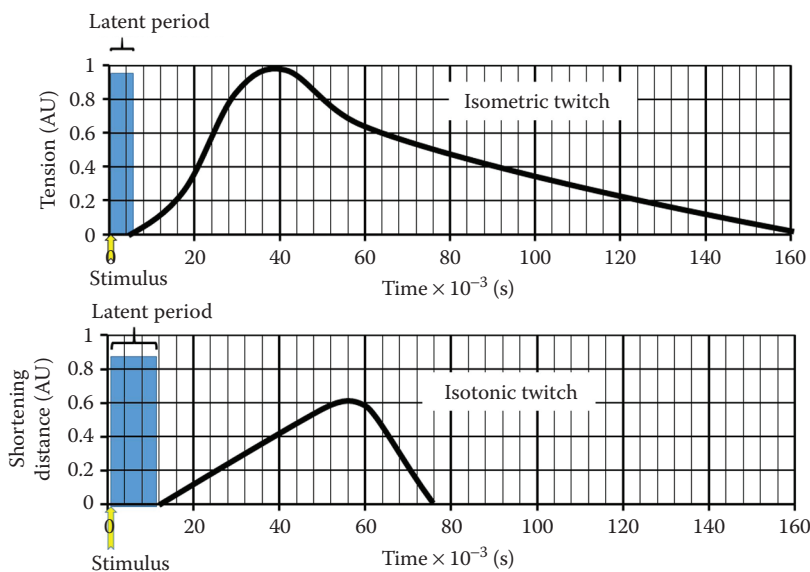


Figure M.164 Force displacement diagram of isometric (constant length) versus isotonic (constant force) muscle contraction, respectively, in response to stimulus from the motor neuron.

Musculoskeletal system

[biomedical, general, mechanics] Biological structure of **MUSCLE** attachment to bones of the skeleton in animals by means of connective tissues including cartilage, tendons, and ligaments. The muscle attachments provides the mechanism to apply a force, or more specifically, a torque which provides stability and the capacity to perform **MOTION**.

Musschenbroek, Pieter van (1692–1761)

[electrical, mathematics, mechanics] See **VAN MUSSCHENBROEK, PIETER**.

Mutual stable equilibrium

[thermodynamics] Subsystems of a composite system that is in a stable **EQUILIBRIUM STATE**, are in mutual stable equilibrium as well. Subsequently, when a composite system is in partial equilibrium the subsystems will be in partial mutual stable equilibrium.

mv (Product of mass and speed)

[general] The momentum (p_{motion}) of an object in **MOTION**: $p_{\text{motion}} = mv$, the momentum changes in response to an impulse (J). The impulse is defined as the summation of all forces (ΣF) applied over a period of time preceding the change in momentum, usually expressed as the integral over **TIME** (t) for the forces $J = \int_{t_1}^{t_2} F dt$.

Myelinated nerve

[biomedical, electronics] Nerve **CELL** with myelin envelop over a short **DISTANCE** at consecutive segments over the entire length of the nerve cell. Certain specialized nerve cells have formed a coalition with a separate cell to create a unique conduction system. Over time the axon is wrapped in patches of fatty, white myelin sheath at regular intervals along the length of the axon. The myelin is a secretion resulting from the **ACTIVITY** of specific cell type called glial cells. Oligodendrocytes produce myelin sheaths that insulate certain vertebrate axons in the central nervous system. Schwann cells have a similar function in the peripheral nervous system. Myelin builds up over time and is not fully formed at birth. The propagation speed for action potentials (conduction rate) of myelinated nerve cells is two orders of **MAGNITUDE** greater than that for unmyelinated nerve cells, switching from 2 m/s to 120 m/s (*also see* **NERVE**) (see [Figure M.165](#)).

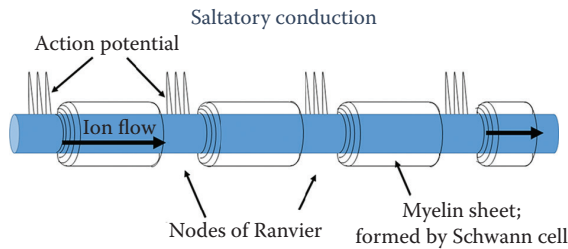


Figure M.165 Outline of the myelinated nerve principles. Description of the action-potential propagation for a myelinated nerve axon.

Myopia

[biomedical, general, optics] Optical property of the **EYE** where far away objects cannot be displayed sharp or in focus on the **RETINA** due to anatomical disorder of the eyeball that place the **LENS** of the eye at a too

great-a-distance to the retina so that the accommodation process will no longer allow for adjustments to fully focus. The far-point of the myopic eye is relatively close, sometimes within meters, or CENTIMETERS instead of infinity. This condition can be corrected by a corrective, DIVERGING LENS, that places the object as a virtual image at a reduced DISTANCE (see Figure M.166).

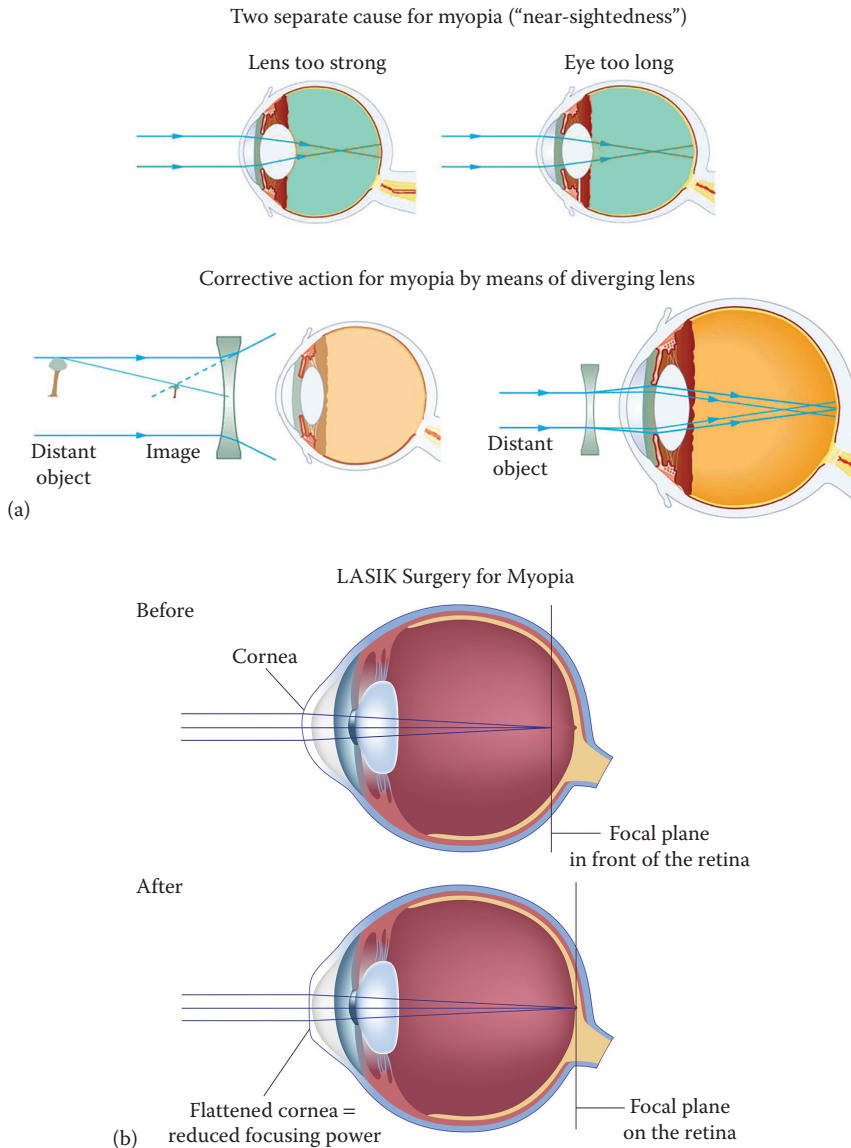


Figure M.166 (a) Myopia and vision correction by means of a lens in front of the eye and (b) the effects of LASIK surgery to correct myopia on a more permanent basis.

Myosin

[biomedical, chemical] Chemical structure working with ACTIN to perform contraction in MUSCLE tissue (see MUSCLE).

Myotis pulse

[acoustics, biomedical, theoretical] Frequency sweep in acoustic scanning for the *Myotis* family of bats during hunting. This specific sweep spans one OCTAVE, for instance, from approximately 40–80 kHz over a specific time span. The time span between pulses generally ranges from 50 to 100 ms in cruising mode (scanning), whereas the pulse interval can decrease to 10–50 ms during attack for hunting mode. In comparison, the acoustic pulse of the *Eptesicus* bat is quite different. For the *Eptesicus* bat, both the sweep speed and the frequency range changes between surveillance mode and hunting mode. In hunting mode the FREQUENCY SPECTRUM is lower (i.e., shorter wavelength range with increased ASSOCIATED RESOLUTION) while simultaneously the pulse length is shorter. This type of SIGNAL PROCESSING is applied in other forms by several other animals. The same principles are applied both in communication as well as in diagnostic scanning applications in both biological and device imaging. For instance, the hawk applies a similar concept in VISION, switching from low resolution scanning to high-resolution hunting, using specifically different anatomic and functional regions of the RETINA, with respective signal processing on different sections of the brain. The device applications vary from mechanism of action to user interface with the operator (see BAT and ECHO-LOCATION) (see Figure M.167).

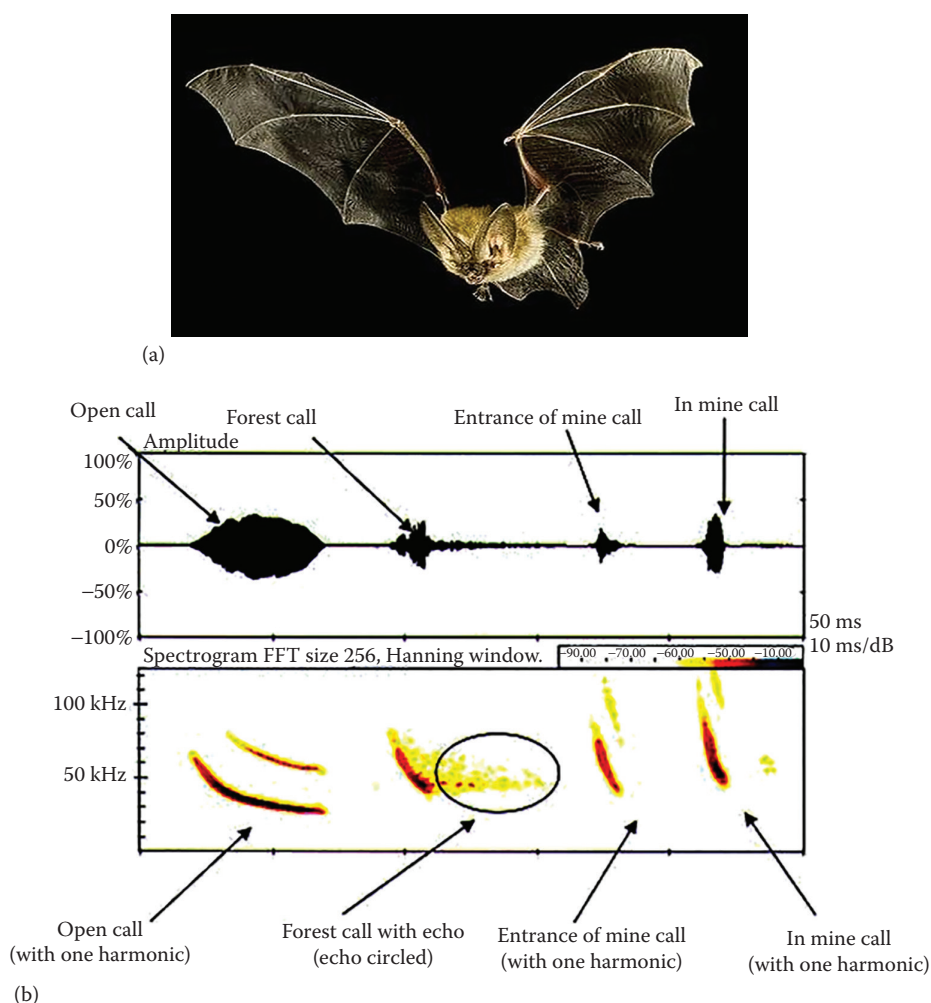


Figure M.167 (a) A bat and (b) the principle and application of the myotis pulse in bats for guidance and recognition of prey during hunting. (Courtesy of "Sarah" acquired during an award winning project with American Museum of Natural History: "The World Through a Bat's Ears"; <http://www.amnh.org/learn-teach/young-naturalist-awards/winning-essays2/2005-winning-essays/the-world-through-a-bat-s-ears>.)

η

[fluid dynamics] (Greek: “eta”), [coefficient of] Viscosity of a FLUID in motion, often confined to an incompressible, irrotational fluid. The ratio of shear stress to velocity gradient: $\eta = (F/A)/(dv_x/dz)$, where F is the force parallel to the surface (A) at which the VISCOSITY is determined, v_x the FLOW velocity and z the DISTANCE perpendicular to the flow. The generally accepted unit for viscosity is *poise* [P], named after the French physiologist JEAN LÉONARD MARIE POISEUILLE (1799–1869). Ten poise equal one Pascal second [Pa s]. The KINEMATIC VISCOSITY (ν_{kin}) is the viscosity per unit DENSITY (ρ): $\nu_{\text{kin}} = \eta/\rho$. The unit for kinematic viscosity is cm^2/s , which equals the unit *stokes*: $1St = 1 \text{ cm}^2/\text{s}$, after the Irish physicist and mathematician GEORGE GABRIEL STOKES (1819–1903) (see [Figure N.1](#)).



Figure N.1 Viscous flow of water from a roof after a rain storm.

N¹³, ¹³nitrogen

[atomic, biomedical] Radioactive isotope of ¹⁴nitrogen (¹³N), which decays to carbon-13 (¹³C) by beta + DECAY (e^+) with a half-life of 9.965 min: $^{13}\text{N} \rightarrow ^{13}\text{C} + e^+ + \nu_e + 1.20 \text{ MeV}$, where e^+ is a positron and ν_e and electron NEUTRINO. N¹³ is used in positron emission TOMOGRAPHY imaging. N¹³ is produced by bombarding oxygen by hydrogen (i.e., PROTON) with kinetic ENERGY of slightly more than 5.55 MeV: $\text{O}^{16} + \text{H}^1 \rightarrow \text{N}^{13} + \text{He}^4$.

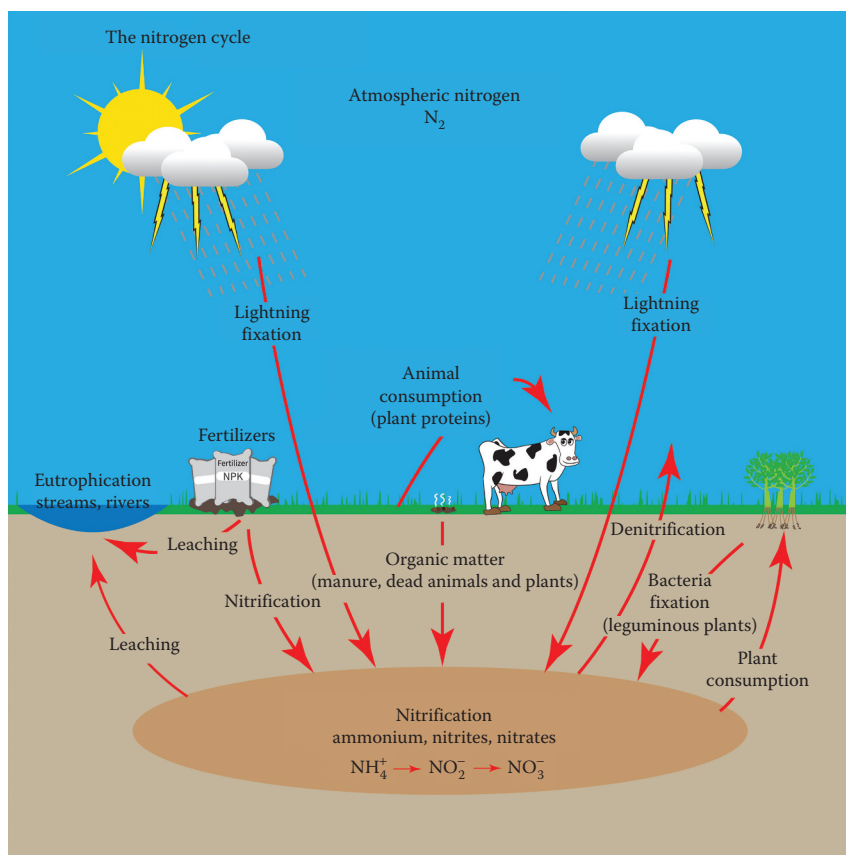
N¹⁴, ¹⁴nitrogen

[atomic, biomedical] Standard nitrogen: ¹⁴N, discovered by the Scottish physician, chemist, and botanist Daniel Rutherford (1749–1819) in 1772. The Earth’s ATMOSPHERE consists of approximately 78% nitrogen as a GAS under standard conditions. Nitrogen has a EVAPORATION temperature (boiling point) at 77.355 K = −195.795°C and a SOLIDIFICATION temperature (MELTING POINT) of 63.15 K = −210.00°C; the TRIPLE POINT is at 63.151 K under pressure of 12.52 kPa, and the critical point is at 126.192 K at

3.3958 MPa. The heat of FUSION for nitrogen is 0.72 kJ/mol and the heat of vaporization for nitrogen is 5.56 kJ/mol. Nitrogen is a popular and effective component of fertilizer. ANTOINE-LAURENT DE LAVOISIER (1743–1794) named nitrogen “mephitic air” referring to the fact that animals would not survive and flames were extinguished when under the inert 100% concentration, a name that is found to carry through in several languages. Evaporating LIQUID nitrogen provides low-rolling clouds of nitrogen and condensate water vapor (see Figure N.2).



(a)



(b)

Figure N.2 (a) Nitrogen in dewar used for refrigeration of samples in test-tubes. (b) Illustration of the atmospheric nitrogen cycle.

Nabla (∇)

[computational, fluid dynamics, mechanics] Differential operator describing the mathematical operator for expressing gradient, DIVERGENCE, or curl. In mathematical expression, the application to a function (f) is ∇f , pronounced as “del f ,” where $\nabla f(x, y, z) = (df/dx, df/dy, df/dz)$; as a Cartesian gradient, this yields $\nabla f(x, y, z) = (df/dx) + (df/dy) + (df/dz)$. As an expression for divergence, the formulation is in “dot” product: $\nabla \cdot f(x, y, z) = \text{div } \mathbf{f}(x, y, z) = (du/dx) + (dv/dy) + (dw/dz)$, where the matrix function $\mathbf{f}(x, y, z) = u\vec{i} + v\vec{j} + w\vec{k}$ with $\vec{i}, \vec{j}, \vec{k}$ the unity directional vectors for the x , y , and z directions, respectively. The curl is a vector operator describing the rotation in infinitesimal steps of a three-dimensional vector field: $(\nabla \times \mathbf{f}) \cdot \vec{n}$, where $\vec{n}$ is the normal vector.

National Advisory Committee for Aeronautics (NACA)

[general] A US federal agency erected in 1915 with the goal to institutionalize aeronautical research as well as to promote and undertake aeronautical activities and exploration. The agency was dissolved in 1958. The assets and its personnel were transferred to the newly created NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA).

National Aeronautics and Space Administration (NASA)

[general] A US agency founded in 1958 under President Dwight David “Ike” Eisenhower (1890–1969; 34th president); it is responsible for aeronautics and aerospace research and the US national civilian space program. Many exploratory rockets and manned space flights have been planned and executed by NASA, following the work initiated by the NACA in 1946 with the launch of the Bell X-1 for exploration of supersonic flight and the early 1950s launch of an artificial SATELLITE following the space journey by Sputnik-1 in 1957 launched by the Union of Soviet Socialist Republics (USSR [Russian: Союз Советских Социалистических Республик: СССР]) (see [Figure N.3](#)).



(a)

Figure N.3 (a) Representation of space flight managed by NASA; Boeing Space Launch System (SLS). (Courtesy of Boeing Corporation.) (Continued)



(b)

Figure N.3 (Continued) (b) NASA space flight emblem.

National Center for Biotechnology Information (NCBI)

[biomedical] A US government-funded national resource for molecular biology information founded in 1988. The NCBI is a subdivision of the US National Library of Medicine (NLM). The NLM is a branch of the US National Institutes of Health.

National Institute of Standards and Technology (NIST)

[general] NIST is the US federal technology agency instituted in 1988; its intention is to work with the industry to develop and apply technology, measurements, and standards. NIST has, for instance, advanced the development of prototype tools for experimental medical imaging techniques for diagnostics of medical conditions. Between 1901 and 1988, it was known as the National Bureau of Standards.

National Institutes of Health (NIH)

[biomedical] An agency of the US Department of Health and Human Services. The primary agency of the US government responsible for all health-related and biomedical research (see [Figure N.4](#)).



Figure N.4 Illustration of the NIH emblem.

[biomedical] The US medical library founded in 1836 and is the largest medical library in the world. The NLM also supports and conducts research. Additionally, the NLM support the development and training in biomedical informatics and health information technology.

Natural angular frequency

[acoustics, general] Resonant frequency of an undamped, unforced OSCILLATOR: $\omega_0 = \sqrt{(k_{\text{spring}}/m)}$, where k_{spring} is the spring-constant for the flexible medium and m the mass of the resonator in MOTION with respect to the flexible medium (i.e., spring). In case the RESONANCE is dampened by a “pod” with dampening coefficient b_{damp} , the frequency for the DRIVEN DAMPED HARMONIC OSCILLATOR becomes the resonant angular frequency: $\omega_{\text{Res}} = \sqrt{(\omega_0^2 - (b_{\text{damp}}^2/2m^2))}$. The NATURAL FREQUENCY (ν_0) associated with the angular frequency ($\nu_0 = \omega_0/2\pi$) is also referred to as the “resonant frequency” (see Figure N.5).



Figure N.5 (a) Metronome, used for setting the pace during a musical performance.

(Continued)



(b)

Figure N.5 (Continued) (b) The pendulum is maintained by gears that rotate under the influence of weights.

Natural convection

[general] Fluid motion as well as HEAT TRANSFER based on thermal gradient; no active mechanism is involved. For instance, BUOYANCY forces driving the FLUID motion due to difference in density resulting from temperature gradients and variations in the fluid, for example, “warm air rise” (*also see CONVECTION*) (see [Figure N.6](#)).

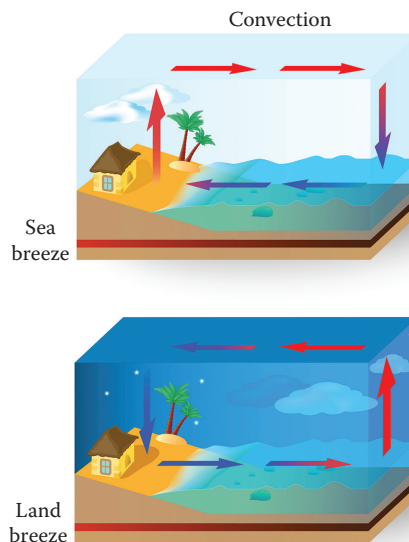


Figure N.6 Natural convection of rising warm air and the ensuing wind generated based on the thermal gradient induced by the differences in specific heat (related terminology: heat capacity or thermal capacity) of land and water masses and the resulting solar heating during the day versus radiant cooling at night.

Natural frequency

[acoustics, electromagnetism, general, mechanics] Resonant phenomena of mechanical devices and electronic circuits based on their composition characteristics (*also see* **HELMHOLTZ RESONATOR**). The natural frequency (ν_0) of a single-opening design (e.g., GLASS bottle; a SOUND is generated when blowing over the open neck of the bottle) is mathematically defined by the physical characteristics including device volume V , cross-sectional area of the ORIFICE A , effective neck length, which includes a correction for the air-volume near the opening (i.e., $\delta\ell$) that flows in and out in order to generate the sound $\ell' = \ell + \delta\ell$, yielding $\nu_0 = v_s / 2\pi\sqrt{A/\ell'V}$, or $\omega(\vec{r}, t) = A\sqrt{E_{\text{mech}}/\rho\ell'^2}$, with v_s the speed of sound, E_{mech} the Young's modules, and A is the constant. The HELMHOLTZ RESONATOR has a behavior similar to a mass-spring harmonic oscillator with mass $m = \rho A\ell'$ and spring-dashpot ELEMENT where for a volume of FLUID, the spring constant is defined by $k = \rho v_s^2 (A^2/V)$. The dampener or DASHPOT will contribute a RESISTANCE R to the ENERGY equation (resulting in extinguishing the AMPLITUDE); however, generally the resonant frequency is in this case defined as $\nu_0 = 1/2\pi\sqrt{k/m}$. Analogously, the RESONANCE FREQUENCY for an electronic circuit with a RESISTOR (R), CAPACITOR (C), and INDUCTOR (L) in series is given as $\nu_0 = 1/2\pi\sqrt{1/LC}$, where the resistor will merely reduce the amplitude as a function of time (see [Figure N.7](#)).



Figure N.7 Tuning fork that will resonate at the natural frequency defined by the metal and geometrical configuration.

Natural light

[general] See SUN LIGHT.

Natural logarithm

[general] Logarithm to the base e , where $e \cong 2.718281828$, written as $\ln x$ or $\log_e x$, where $\ln a = \int_1^a (1/x)dx$, also known as “hyperbolic logarithm.” The concept of the natural logarithm was documented back to 1619 in tabulated solutions by John Speidell (~1600 to ~1635?), but was officially mentioned in 1668, by the German scientist and land surveyor Nicholas (Nikolaus) Mercator (1620–1687) in his work *Logarithmotechnia* (*also see* **LOGARITHM**).

Natural materials

[biomedical] Materials that are biocompatible with the biological nature, can be integrated in biological units (e.g., prosthetic devices and PACEMAKER), or can degrade without release of toxic components (e.g., SCAFFOLD for tissue ENGINEERING and regenerative medicine).

Navier, Claude-Louis Marie Henri (1785–1836)

[computational, fluid dynamics, general] An engineer and scientist from France. Known for his FLUID DYNAMICS work, specifically describing the equation of MOTION behavior of an INCOMPRESSIBLE FLUID (the NAVIER–STOKES EQUATION) and the follow-up by SIR GEORGE GABRIEL STOKES (1819–1903), and in MECHANICS defining the general theory of ELASTICITY in a convenient mathematical form in 1821. In 1826, Claude Navier defined the ELASTIC MODULUS as a material property (see [Figure N.8](#)).



Figure N.8 Claude-Louis Marie Henri Navier (1785–1836): bust erected at the École Nationale des Ponts et Chaussées in Paris, France.

Navier–Stokes equation, viscous fluid

[energy, fluid dynamics, general] Equation of MOTION, specifically for FLUID behavior, defined by the work of CLAUDE-LOUIS NAVIER (1785–1836) in 1822, and later refined by SIR GEORGE GABRIEL STOKES (1819–1903). The following definitions are used in the description of the Navier–Stokes equations for FLOW: the three-dimensional flow velocity is defined by $\vec{u} = (u, v, w)$, Cartesian coordinate system $\vec{x} = (x, y, z)$, ∇ is the Laplace operator, P the pressure, Q resp. q the heat flux, $\vec{g} = (g_x, g_y, g_z)$ gravitational orientation with respect to flow ELEMENT, E_t the total ENERGY of the system, Pr is the Prandtl number, Re is the REYNOLDS NUMBER, ρ is the density of the fluid,

$$\tau = \begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix}$$

defines shear stress, with σ the normal stress: for example, $\sigma_{xx} = (F_x/A_x)$, F_x the force ($\vec{F}$) acting in the x direction over a presumed contact surface: $A_x \mu$ the dynamic VISCOSITY, and λ the secondary

viscosity (which is zero for incompressible flow) The following Navier–Stokes equations are available to describe three-dimensional UNSTEADY FLOW phenomena. The EQUATION OF CONTINUITY reads $\partial\rho/\partial t + \partial(\rho u)/\partial x + \partial(\rho v)/\partial y + \partial(\rho z)/\partial z = 0$. The momentum equations (in CARTESIAN COORDINATES) for incompressible fluids are as follows:

$$\begin{aligned} \rho g_x - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x} \left[2\mu \frac{\partial u}{\partial x} + \lambda \nabla \cdot \vec{u} \right] + \frac{\partial}{\partial y} \left[\mu \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] + \frac{\partial}{\partial z} \left[\mu \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right] \\ = \rho \left[\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right], \end{aligned}$$

respectively

$$\begin{aligned} \rho g_y - \frac{\partial P}{\partial y} + \frac{\partial}{\partial y} \left[2\mu \frac{\partial v}{\partial y} + \lambda \nabla \cdot \vec{u} \right] + \frac{\partial}{\partial x} \left[\mu \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \right] + \frac{\partial}{\partial z} \left[\mu \left(\frac{\partial w}{\partial y} + \frac{\partial u}{\partial z} \right) \right] \\ = \rho \left[\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right], \end{aligned}$$

and

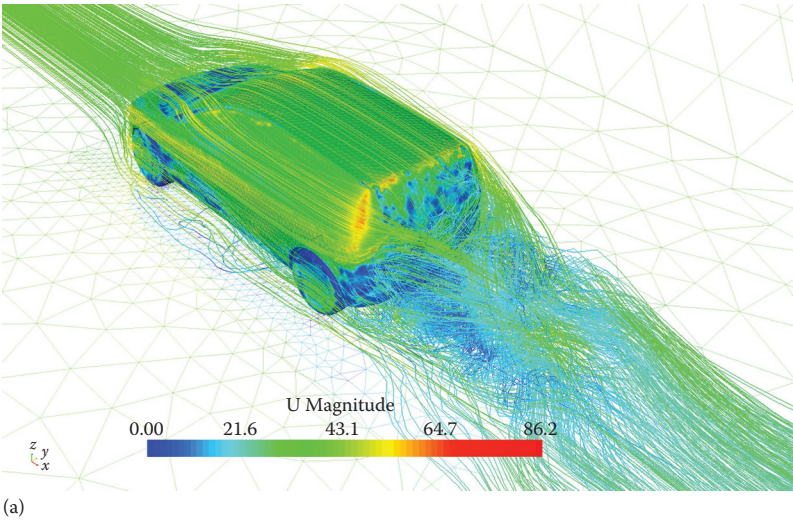
$$\begin{aligned} \rho g_z - \frac{\partial P}{\partial z} + \frac{\partial}{\partial z} \left[2\mu \frac{\partial w}{\partial z} + \lambda \nabla \cdot \vec{u} \right] + \frac{\partial}{\partial x} \left[\mu \left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \right) \right] + \frac{\partial}{\partial y} \left[\mu \left(\frac{\partial w}{\partial y} + \frac{\partial u}{\partial z} \right) \right] \\ = \rho \left[\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right]. \end{aligned}$$

The energy of the flow system is defined by

$$\begin{aligned} \partial(E_t)/\partial t + \partial(uE_t)/\partial x + \partial(vE_t)/\partial y + \partial(zE_t)/\partial z \\ = -\partial(uP)/\partial x - \partial(vP)/\partial y - \partial(zP)/\partial z. \end{aligned}$$

In the case of flow around a prolate spheroid, the unsteady Navier–Stokes equations for incompressible flow at a function of TIME (t) are written as $\nabla \cdot \vec{u} = 0$ and $\partial \vec{u}/\partial t + \vec{u} \cdot \nabla \vec{u} = -\nabla \vec{P} + (1/Re_\infty) \nabla^2 \vec{u}$, and Re_∞ the Reynolds number based on the freestream flow velocity u_∞ . A prolate spheroid is a spheroid that is narrower

in the direction of flow than perpendicular to the flow, with d the diameter of the spheroid in the direction of flow; in contrast to a “squashed” spheroid, which will be wider in the direction of flow. (see Figure N.9).



(a)

Condition	Navier–Stokes equations 3-dimensional unsteady			Glenn Research Center
Coordinates: (x,y,z)	Time: t	Pressure: p	Heat flux: q	
Velocity components: (u,v,w)	Density: ρ	Stress: τ	Reynolds number: Re	
	Total energy: E_t		Prandtl number: Pr	
Continuity:	$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$			
X-momentum:	$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r} \left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} \right]$			
Y-momentum:	$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r} \left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} \right]$			
Z-momentum:	$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r} \left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \right]$			
Energy:	$\frac{\partial(E_r)}{\partial t} + \frac{\partial(uE_r)}{\partial x} + \frac{\partial(vE_r)}{\partial y} + \frac{\partial(wE_r)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r} \left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z} \right]$			
(b)	$+ \frac{1}{Re_r} \left[\frac{\partial}{\partial x} (u\tau_{xx} + v\tau_{xy} + w\tau_{xz}) + \frac{\partial}{\partial y} (u\tau_{xy} + v\tau_{yy} + w\tau_{yz}) + \frac{\partial}{\partial z} (u\tau_{xz} + v\tau_{yz} + w\tau_{zz}) \right]$			

(b)

Figure N.9 (a) Computer simulation of flow around a car (Courtesy of Johan Hoffman and Claes Johnson and G2 FEniCS software; <http://www.bodysoulmath.org/>) based on Navier–Stokes equations. (Courtesy of Johan Hoffman and Claes Johnson and G2 FEniCS software, <http://www.bodysoulmath.org/>.) (b) Compressible flow Navier–Stokes equations. (Courtesy of NASA.)

NDE

[acoustics, electromagnetism, general, mechanics] See NONDESTRUCTIVE EVALUATION. It is also known as “nondestructive testing in quality control”.

Near point

[general, optics] The closet point to the EYE that can be observed with optimal accommodation. For the average human this point changes with AGE and is generally takes as 25 cm for a healthy young eye. By the age of 40, the near point, where a person can read comfortably at closest DISTANCE, can be increased to 40 cm (see [Figure N.10](#)).



Figure N.10 Illustration of the near-point for vision requiring corrective lenses.

Nearest-neighbor interpolation

[acoustics, computational, general] The data point closest to the requested x value data point on the phenomenological basis for a function ($f(x)$) with outcome is used to estimate the matching $f(x) = y$ value for the desired value. Interpolation is the process used to determine the missing values of a function based on the known values. There are four approximation methods available: nearest-neighbor interpolation, linear interpolation, polynomial interpolation, and spline interpolation.

Nearfield acoustic holography

[acoustics] Principle of acoustical imaging using an array of detectors to reconstruct the exact source location of an acoustic perturbation resulting from incident sound waves with respect to an acoustic discontinuity in a medium. In the near-field approach, the MICROPHONE array is placed in relative close proximity to the SOUND source array. The near field is generally defined as less than two wavelengths DISTANCE pertaining to the highest frequency used by the source. Often, this can be accomplished by using the source material as the detector, as in piezoelectric devices. This mechanism is of general application in ULTRASONIC IMAGING, specifically three-dimensional imaging. The mechanism of action is limited by the following two selection criteria, which both put requirements on the source operations and frequency band: spatial RESOLUTION, the ability to separate two sound sources, and dynamic range, sound MAGNITUDE level differences in dB between real secondary sound sources and the immediate surrounding mathematical artifacts. The imaging process is based on the following three steps: (1) transform the acoustical pressure field by spatial FOURIER TRANSFORM from the spatial domain to the WAVE number domain, (2) use the Dirichlet Green function to analyze the backpropagation of the different waves to the new defined plane, and (3) apply inverse spatial fourier transform to convert the ACOUSTICS signal from the wave number domain to

the spatial domain. The imaging planes are restricted to an orientation that can only be parallel with the detection array (see Figure N.11).

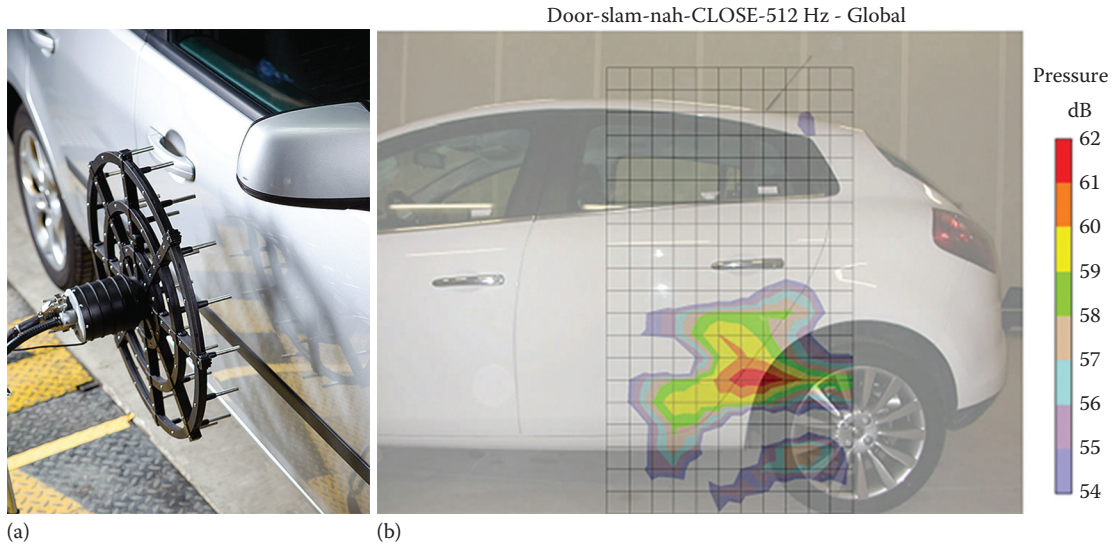


Figure N.11 (a) Illustration of a nearfield acoustic holography camera. (b) Image acquired by camera. (Courtesy of Designworld online; as produced by LMS International/Siemens.)

Near-field scanning optical microscope (NSOM)

[optics] The NSOM utilizes the fact that observations are made from a **DISTANCE** to the object under investigation at less than, or in the order of the interrogating wavelength. The illumination of the sample is also provided by a source with dimensions less than the wavelength. In addition, the NSOM does not provide an instantaneous global view of a section of the sample under investigation; however, the object is probed (scanned) in the near-field of the sample surface, by moving the source and/or detector across the specimen in nanometer steps, hence the name. A total **IMAGE** is formed with **RESOLUTION** less than the Abbe limit, after a series of line scans is performed, and all the intensity arrays are combined. Even though the NSOM is a relatively new instrument (inception 1982, Dieter Wolfgang Pohl and W. Denk), the concept was described in letter exchanges between Edward Hutchinson Synge and Albert Einstein in 1928. NSOM is an optical microscope that provides high spatial resolution capabilities with light sources in the visible spectrum. There is no high demand on sample preparation or confinements on working environments with NSOM. Thus far, it has been shown that working within the near field generates high spatial frequency information. However, what is needed in an optical microscope is high spatial frequency information on a subwavelength scale. Most explanations of the diffraction **BARRIER** on spatial resolution capabilities, take in account just the diffraction of light as it propagates through a collection **LENS** of a far-field optical system. Light will interact with the edges of the circular **APERTURE** of the lens causing the deviation of light from its initial line of travel. However, it is not just the interaction of the light with the collection lens that limits the resolution, but there exist the effects of the light interacting with detail in the sample structure. In the initial developmental stages of NSOM, the proposition was made for an optical microscope in which light would pass through a subwavelength aperture in an **OPAQUE** screen, illuminating an object directly below the screen. The screen would be maintained at a constant **DISTANCE** of a few nanometers from the sample surface, placing the sample in the near field. The idea is that the transmitted radiation would remain collimated, as it interacts with the sample. Therefore, a subwavelength beam interacts with a small volume **ELEMENT** of the sample, and this light that interacts with the sample is collected by an objective. The sample is basically broken into small **PIXEL** areas. The subwavelength **LIGHT SOURCE** would be scanned over

each pixel area, generating a two-dimensional intensity image. There are two theoretical parameters that give the near-field scanning optical microscope the high spatial resolution capabilities. The first theoretical boundary condition is that the sample is maintained in the near field by keeping the sub wavelength aperture a constant height above the sample surface. The second condition is that the spot size of the light that interacts with the sample is confined to the dimensions of the sub wavelength aperture. The combined effect of these two parameters yields high spatial frequency information on the sub wavelength scale. General design of NSOM microscope is as follows. The near-field scanning optical microscope can take on many different forms, depending on the user's specific application. Typically, the near-field scanning optical microscope is constructed on top of an inverted microscope. The inverted microscope allows the user to target specific areas on the sample surface before any high-resolution imaging is performed. First, laser light is passed through a bandpass filter to remove any undesirable wavelengths. The bandpass filter is followed by some wave plates, which are used to control the POLARIZATION state of the laser light. The light is then coupled into a single mode optical fiber via a launcher. The end of this single mode optical fiber is heated and pulled or chemically etched to form a subwavelength aperture. The small near-field resolution is primarily due to the tapered fiber tip design. The very end of the single mode optical fiber, where the subwavelength aperture was fabricated, is mounted to an atomic force microscope (AFM). The AFM head will be discussed in more detail, but it is part of the mechanism that is used to maintain the subwavelength light source at a constant height above the sample surface. The light is transmitted through the subwavelength aperture and impinges upon the sample that is mounted to an XYZ piezoelectric translation stage. This XYZ translation stage is used to scan the nanoscopic light source over each pixel area described earlier. The light interacts with a small volume element of the sample, and then, it is collected by the inverted microscope's objective. The collected light is optically guided out of the inverted microscope where it is sent to a detector. The type of detector that is used at the output of the NSOM depends directly on the desired application in which the system is being used. The optical information from each pixel that is measured by the output detector is sent to a computer. The computer is used to construct a high-resolution image of the sample and to run the ELECTRONICS involved in scanning.

NSOM Tip

The NSOM tip is the most essential part of the imaging device and requires that great care is taken in its preparation. NSOM tips have taken on many different shapes, sizes, and material make up. Most of the earlier NSOM tips suffered low transmission of coupled light and poor reproducibility. However, the most widely used NSOM tip design was adopted from Bell Labs. In the early 1990s, Bell Labs proposed a tapered single-mode optical fiber with a reflective metal coating as a design for an NSOM tip. These NSOM tips that are made from optical fiber are fabricated in two different ways, heating and pulling or chemically etching the fiber. In heating and pulling the optical fiber, a commercial micropipette puller is used in the fabrication process. Essentially, a laser is used to heat the optical material, and the fiber is then pulled to a fine point. At the tip of this point, an APERTURE with a diameter on the order of 50–100 nm is formed. One can carefully control the heating and pulling parameters, making this method of fabrication highly reproducible. On the other hand, chemical etching utilizes a SOLUTION that consists of hydrofluoric ACID with an organic buffer layer on top to fabricate the optical fiber. One end of a single-mode optical fiber that has been stripped of its cladding is immersed into the etching solution, which consists of a buffer layer on top of hydrofluoric acid. A MENISCUS is formed in two different locations along the fiber, due to electrostatic interactions between the solution's components and the fiber. However, the etching process only occurs at the organic solvent/hydrofluoric acid interface. As the diameter of the immersed optical fiber in the HF decreases with time, the height of the meniscus formed at the solvent/HF interface decreases. Over a period of time, the etching process is terminated and a tip is formed. The conical shape of the tip can be adjusted by changing the organic SOLVENT that is used in the etching solution. Although there now is a sub-wavelength aperture formed at the end of the single-mode optical fiber, the fabrication process is not complete. There still exists the need to coat the NSOM tip with a reflective metal. The reason for this metallic coating is related to the mode-field structure that propagates through an optical fiber. The ability of a single-mode optical fiber to guide and confine one wavelength of light is directly related to the dimensions and material composition of the optical fiber. As the diameter of the single-mode optical fiber decreases in the tapered region, the ability of the fiber

to confine and guide the light is lost. Therefore, the light is no longer confined to just propagate out of the subwavelength aperture; it escapes out of the sides of the tapered region. High spatial RESOLUTION capabilities of the near-field scanning optical microscope depend strongly on the fact that the beam spot size is to be confined to the subwavelength aperture. The metallic coating applied to the tapered region is required to prevent the leakage of light. This metallic coating also attenuates the light before it can escape. The NSOM tip proposed by Bell Labs, although the most widely accepted, is prone to some inefficiency problems. One such problem has to do with the amount of light that can be transmitted through the subwavelength aperture. A large quantity of light is lost by tip design itself, or the REFLECTION of the light back up through the fiber from the tapered region. Therefore, only a small fraction of the initial coupled light from the source is transmitted through the aperture. This inefficiency tends to limit the applications of NSOM. Feedback mechanisms employed to maintain a constant tip and sample separation. In order to achieve high-resolution imaging capability, an NSOM must employ another specific feature. The NSOM tip needs to be maintained at a constant height of a few nanometers from the sample surface during scanning. There are various techniques that can be employed to maintain a constant DISTANCE between the tip and the sample surface. However, only two of these techniques have become widely adopted by NSOM designers. Shear force tip feedback and tapping-mode feedback have their foundations in atomic force microscopy. These are the most reliable two methods available to maintain a constant tip and sample separation. Both methods involve the mounting of the NSOM tip to a QUARTZ tuning fork and driving the fork/tip system at mechanical resonance. However, one technique dithers the NSOM tip laterally in reference to the sample surface and the other dithers the tip perpendicularly.

Shear-force-mode tip feedback

The tuning fork uses shear-force tip feedback method, where the tip is dithered laterally in reference to the sample surface. An NSOM tip is rigidly attached to one arm of a quartz tuning fork that has a well-defined RESONANCE FREQUENCY of 32.768 kHz and a QUALITY FACTOR, Q , of around 7500 in AIR. Typically, the tip is mounted to the QUARTZ tuning fork using some sort of glue or epoxy. This fork/tip system has a new resonance frequency that is slightly lower than that of the quartz tuning fork, and a quality factor, Q , that ranges from 150 to 300. The fork/tip system is driven at mechanical resonance either by directly applying a sinusoidal voltage to the fork or by applying a sinusoidal voltage to a piezoelectric tube that shakes the fork/tip system at resonance. However, we will only discuss the situation in which the fork/tip system is mounted to a piezoelectric tube that shakes the fork/tip system at mechanical resonance. The quartz tuning fork is piezoelectric in nature. Therefore, the shaking of the fork/tip system at mechanical resonance induces a periodic voltage across the tuning fork that can be monitored through contacts integrated in each arm of the fork. As the resonating fork/tip system approaches the sample surface within a few nanometers, the NSOM tip experiences frictional forces. These frictional forces cause the fork/tip system to become damped, and the amount of DAMPING can be measured through the integrated contacts in each arm of the fork. Essentially, this resonating fork/tip system can be used as a mechanical pick-up for the frictional forces that cause damping. This measured voltage across the quartz tuning fork can be used in a closed loop feedback mechanism, which employs a lock-in amplifier and proportional integral (P.I.) electronic circuit, to maintain the NSOM tip at a constant DISTANCE from the sample surface. As the fork/tip system is brought close to the sample surface, frictional forces interacting with the NSOM tip causes the monitored potential across the fork to decrease in AMPLITUDE and shift in PHASE, any shift from 90° out of phase with the reference, generates an output voltage from the lock-in. An active feedback voltage is sent from the lock-in to the P.I circuit. The P.I circuit sends an immediate response voltage to the XYZ piezoelectric translation stage to adjust the z -position of the stage, in order to maintain the monitored potential at resonance.

Tapping-mode tip feedback: Tapping-mode feedback has also been employed to maintain the NSOM tip at a constant height above the sample surface. It is a more sensitive mechanical pick-up for the frictional forces that interact with the NSOM tip. However, the bend in the tip reduces the throughput efficiency. Therefore, in certain applications that require a relatively high intensity to interact with the sample, shear-force tip feedback will be chosen over tapping-mode feedback. The fork/tip system and the piezoelectric tube form the AFM head that was mentioned earlier in the shear-force mechanism. Essentially, an atomic force MICROSCOPE has been integrated into the NSOM. The atomic force microscope consists of the lock-in

amplifier, P.I circuit, and xyz piezoelectric stage, which are employed in a closed-loop feedback mechanism. As the tip is being scanned across the sample, that has some surface variations, the z-position of the piezo-electric stage is adjusted to maintain the monitored potential across the fork at resonance. A topography IMAGE can be formed serially, pixel by pixel, by monitoring z-voltage that has to be applied to the positioning stage. The beauty of having the atomic force microscope integrated into the NSOM is that intensity and topography images can be built simultaneously.

Intensity imaging

Most biological samples that are studied are very thin and transparent. There are not a great deal of contrast mechanism within the sample to exploit. Therefore, samples have to be treated with dyes, even in NSOM imaging. Typically, samples are stained with dyes that have specific ABSORPTION SPECTRUM. The stained samples are deposited on a piece of mica or a MICROSCOPE cover slip, and air-dried. A sample is mounted to the xyz piezoelectric stage, which scans the sample under the fixed NSOM tip. The light excites fluorescence in the sample is collected by the collection LENS of the inverted microscope. The collected light is optically guided out of the inverted microscope and is passed through a notch filter. The notch filter is used to separate the FLUORESCENCE from any laser light that may be propagating through the system. The light is sent to a high quantum efficiency detector, such as an avalanche photo DIODE operating in single PHOTON count mode. The detector measures the frequency at which photons strike the sensing ELEMENT in the detector.

Phase imaging

Additional work is being done to extend the capabilities of NSOM to include phase imaging. In order to achieve high-resolution subwavelength phase-contrast images an NSOM is integrated into an INTERFEROMETER. The ability to construct high-resolution phase images would have a huge impact in the study of biological samples. Samples would no longer need to be treated with dyes to have a contrast mechanism to exploit. This method would be one step closer to providing a system that could be used to IMAGE living cells. Since NSOM makes use of an optical fiber to achieve subwavelength RESOLUTION capabilities, a hybrid Mach–Zehnder interferometer utilizing an all fiber bidirectional coupler represents the system of choice. The Mach–Zehnder interferometer relies on the same phase sensitive information as described for the other interferometers. Only this time the recombination takes place after transmission instead of REFLECTION. (see [Figure N.12](#)).

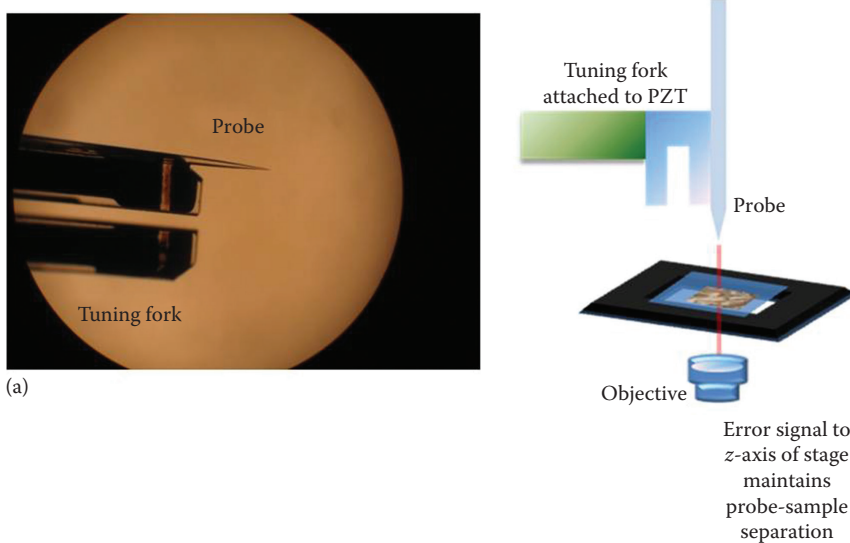


Figure N.12 (a) Nearfield scanning optical microscope. (Courtesy of Kert Edward, University of North Carolina at Charlotte, Charlotte, North Carolina.) (Continued)

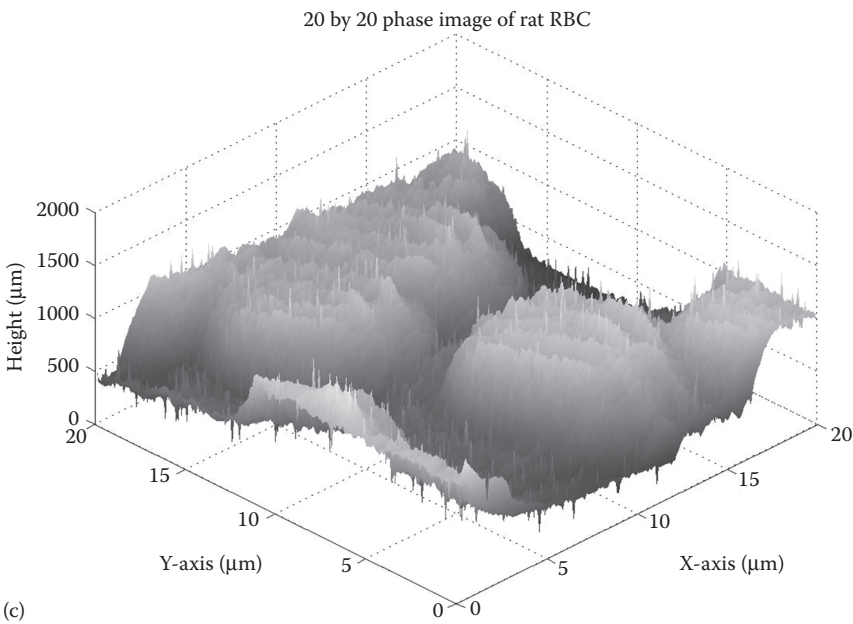
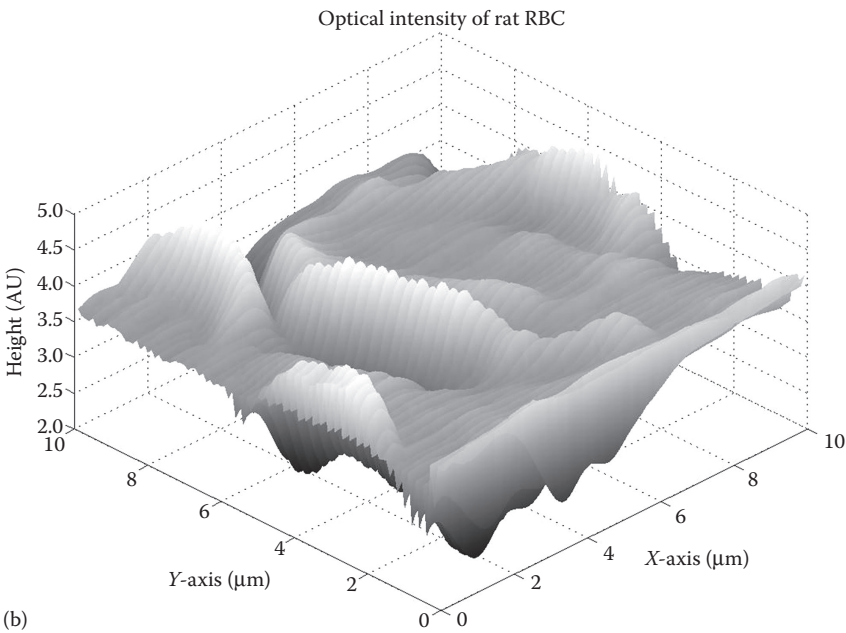


Figure N.12 (Continued) (b,c) Images acquired by means of NSOM methodology. (Courtesy of Kert Edward, University of North Carolina at Charlotte, Charlotte, North Carolina.) (Continued)

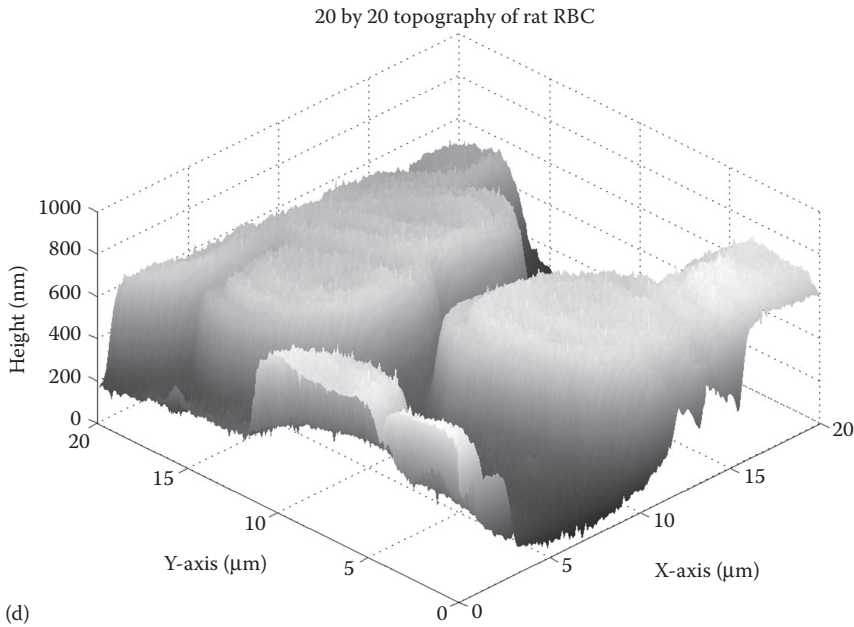


Figure N.12 (Continued) (d) Images acquired by means of NSOM methodology. (Courtesy of Kert Edward, University of North Carolina at Charlotte, Charlotte, North Carolina.)

Nearsightedness

[biomedical, general, optics] *See* MYOPIA.

Necheles, Heinrich (1897–1979)

[biomedical] A physiologist and scientist from Germany that implemented anticoagulation in the dialysis process for BLOOD filtration in people with KIDNEY malfunctions (see [Figure N.13](#)).



Figure N.13 Heinrich Necheles (1897–1979). (Courtesy of *Hektoen International Journal*, Hektoen Institute of Medicine, Chicago, IL.)

Necking

[general] An **ENGINEERING** process that deforms a ductile instrument or device by application of tensile force. Tensile deformation that induces relatively large amounts of strain are rearranged disproportionately in a small volume of the material, resulting in a slimming down process (see [Figure N.14](#)).

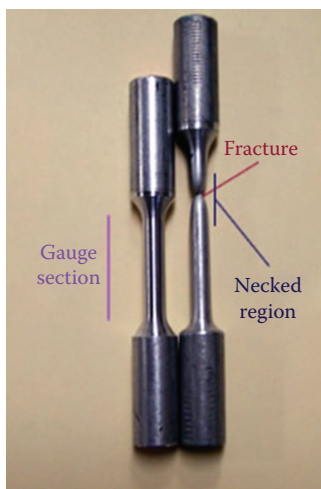


Figure N.14 The process of necking for a narrow metal rod under tensile force applied by an Instron® testing machine.

Neddermeyer, Seth Henry (1907–1988)

[atomic, nuclear] A scientist from the United States who worked on the **MANHATTAN PROJECT** (see [Figure N.15](#)).



Figure N.15 Seth Henry Neddermeyer (1907–1988). (Courtesy of Los Alamos National Laboratory, Los Alamos, NM.)

Needle valve

[fluid dynamics] Valve that uses the adjustable opening from a tapered needle in an ORIFICE of FLOW for flow control. The VALVE will have a loss factor that is nonlinearly proportional to the total opening area. Additional loss in flow may result from TURBULENCE and CAVITATION (see [Figure N.16](#)).

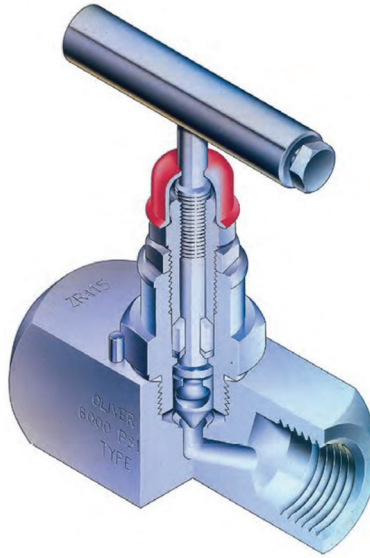


Figure N.16 Needle valve. (Courtesy of Oliver Valves.)

Negative acceleration

[general] Acceleration in direction opposite to the direction of MOTION, resulting in a reduction in velocity, for example, applying the brakes.

Negative charge

[general] Charge consisting of a collection of electrons.

Negative kinetic energy

[nuclear, quantum] In QUANTUM MECHANICS, negative kinetic energy is a SOLUTION to the SCHRÖDINGER EQUATION involving QUANTUM TUNNELING. In general, there is no real negative kinetic energy. In the process of TUNNELING the momentum (classical mechanic, nonrelativistic: $p = mv$, where v is the velocity of mass m ; however, in quantum MECHANICS, the value is a solution to the Schrödinger equation) will have an imaginary value as well as an imaginary WAVE number, and hence “virtual” negative kinetic energy (since by definition $KE = p^2/2m$).

Negative lenses

[general] Lens with at least one concave surface, and hence a virtual FOCAL POINT and is diverging (see LENS).

Negative magnification

[general] Reduction in IMAGE size with respect to object (see MAGNIFICATION).

Negative temperature

[quantum, thermodynamics] Situation where electrons in a very low ENERGY state at micro Kelvin temperature that are virtually not able to move due to the fact that the POTENTIAL WELL is deep and narrow, which is inverted to a potential crest by manipulating the LATTICE. The crest is very stable and the energy cannot go down, and is hence considered “negative.” This concept of temperature is directly linked to the entropy of the system in a QUANTUM STATE, not anymore to the MOTION as in classical MECHANICS.

Nephelometer

[biomedical, fluid dynamics, geophysics, thermodynamics] The stationary or portable analytical instrument that can be applied to measure and analyze the light-scattering coefficient of atmospheric and laboratory aerosols to determine the concentration of suspended particulates in a LIQUID or GAS colloid. The nephelometer specifically gauges the stray light outside the path of incidence, hence determining the scattering CROSS SECTION. Specific applications are in drug solubility screening, and other general nephelometric measurements. The biomedical use relates specifically to immunological assay analysis, the principles of nephelometry rely on the reactions between antibodies and antigens. Antibodies in this realm are specific proteins of the immune system, whereas the antigens are the foreign proteins that can be a threat. Antibodies are very specific and selective in their association with particular antigens and will bind strongly to it (see [Figure N.17](#)).

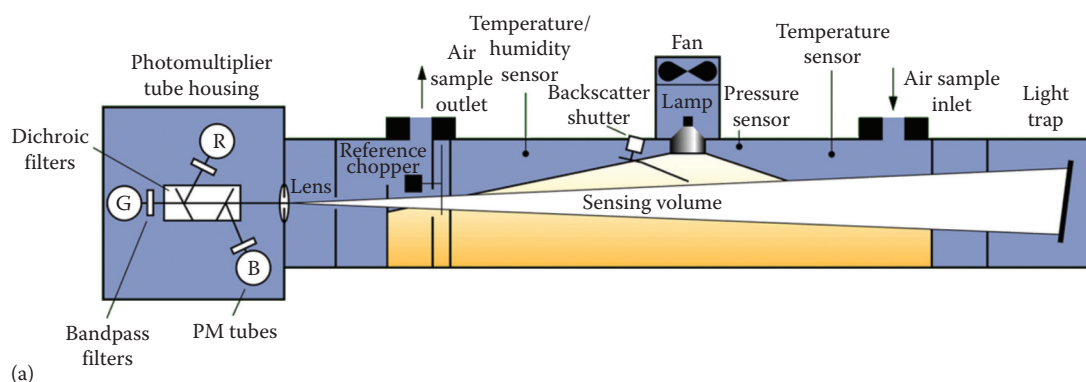


Figure N.17 (a) Outline of Nephelometer, this one in particular operating at 550 nm. (Courtesy of Lynn Russell, Princeton University, Princeton, NJ.) (b) Professional Sensidyne Nephelometer. (Image courtesy of Sensidyne, LP—www.Sensidyne.com.)

Neptunium ($^{237}_{93}\text{Np}$)

[atomic, nuclear] Metallic ELEMENT discovered in 1940. The first ISOTOPE was produced in the University of California, Berkeley by Edwin Mattison McMillian (1907–1991) and Philip Hauge Abelson (1913–2004) by bombarding uranium with slow moving neutrons, creating neptunium-239, with a half-life of approximately 2.3–2.4 days, decays to plutonium-239 by beta DECAY. The most stable configuration is neptunium-237, discovered in 1942 by A. C. Wahl and Glenn T. Seaborg, has a half-life of 2,144,000 years, decays into protactinium-233 through ALPHA DECAY and is a by-product of the production of PLUTONIUM ($^{244}_{94}\text{Pu}$).

Nernst, Walther Hermann (1864–1941)

[biomedical, chemical, energy, thermodynamics] A German physicist and chemist who contributed to the model of the electrical stimulus propagation in biological communications, on a chemical (ionic) basis. Nernst was born in Wąbrzeźno, at the time Briesen part of the Prussian ("German") Empire now Poland. Walther Nernst is best known for his work in electrochemical applications in biology. More generally, the electrochemical efforts were focused on galvanic cells, such as the BATTERY. The galvanic NERNST POTENTIAL describes the electrical potential resulting from a CHEMICAL GRADIENT. The Nernst potential is the pivotal instrument in the HODGKIN–HUXLEY MODEL of propagation of electrical DEPOLARIZATION along the length of a nerve CELL. The electrical gradient across the cellular membrane is directly related to the VAN'T HOFF EQUATION or with respect to the OSMOTIC PRESSURE across a SEMIPERMEABLE MEMBRANE. Nernst received the Nobel Prize (1920) for his contributions to the chemical embodiment of the THIRD LAW OF THERMODYNAMICS applied to chemical affinity (see [Figure N.18](#)).

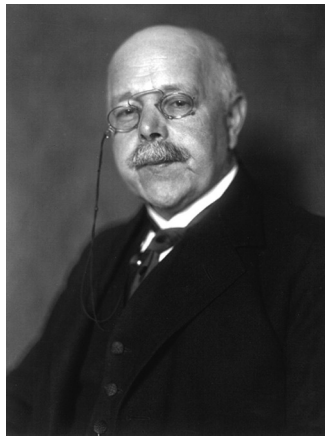


Figure N.18 Walther Hermann Nernst (1864–1941).

Nernst equation

[biomedical, chemical, thermodynamics] The electrical transmembrane potential resulting from a ION gradient expressed by Walter Nernst (1864–1941) as $\Delta V = \Delta V^\circ - (RT/nF_{\text{far}})\ln Q_r$, where $R = 8.3144621(75) \text{ J/Mmol}$ is the GAS constant, T is the (absolute) temperature, n is the number of transferred charges, Q_r is the reaction quotient, $F_{\text{far}} = 96485 \text{ C/mol}$ is the FARADAY CONSTANT, and ΔV° is the maximum POTENTIAL DIFFERENCE due to the MOTION of charges at normal conditions (temperature and pressure). The biological membrane potential was later defined more rigorously by the Goldman voltage equation.

Nernst potential

[biochemical, chemical, thermodynamics] See NERNST EQUATION.

Nernst principle

[thermodynamics] Theory of the electromotive force that defines the electrical potential of the voltaic CELL (i.e., BATTERY) developed by Walter Nernst (1864–1941) in 1888. The principle describes the change in free ENERGY from the chemical reaction that leads to the current produced. The GIBBS FREE ENERGY (G) is the energy that determines whether a reaction will be spontaneous or not. It is defined as the change in ENTHALPY (H) minus the TEMPERATURE (T) times the ENTROPY (S): $\Delta G = \Delta H - T\Delta S = \Delta U + P\Delta V - T\Delta S = \Delta G_0 + RT \ln Q_r$, where P is the pressure, U is the internal energy, V is the volume, $R = 8.3144621(75)$ J/Kmol is the GAS constant, and Q_r is the reaction quotient. Later this was summarized in the NERNST EQUATION.

Nernst–Planck diffusion equation

[biomedical, chemical, thermodynamics] The FLUX of ions across a membrane $\bar{J}_K$ [current/area] is calculated as a function of the concentration of the species of interest $[C_K]$, the DIFFUSION constant D_K : $\bar{J}_K = -D_K (\nabla[C_K] + ([C_K]/\alpha_K)\nabla V)$, where $\alpha_K = RT/F_{\text{far}}Z_K$ is the ION transfer rate, Z_K is the VALENCE of the ionic constituents in the diffusion process, $F_{\text{far}} = 96,485$ C/mol is the FARADAY CONSTANT, $R = 8.3144621(75)$ J/Kmol is the GAS constant, and T is the (absolute) temperature. It was described by WALTER NERNST (1864–1941) and ERNST PLANCK (1858–1947).

Neumann, Carl (Karl) Gottfried (1832–1925)

[computational, material] Scientist and mathematician from Prussia (now Germany). Neumann is best known for his pioneering work in the development of integral equations, as well as the NEUMANN SERIES. In 1875, Neumann also introduced the notation $\bar{d}$, representing an “inexact” differentiation associated predominantly with heat and work that depend on the path in which the differentiation is taken, later replaced by the symbol δ by James Riddick Parlington (1886–1965) in 1924, a chemist and thermodynamic physicist from Great Britain (*Note*: James Parlington worked under Walther Nernst [1864–1941]) (see [Figure N.19](#)).

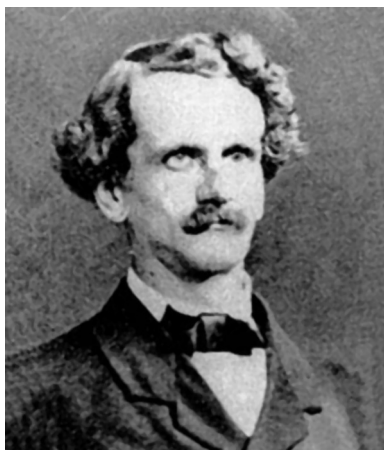


Figure N.19 Carl (Karl) Gottfried Neumann (1832–1925).

Neumann boundary condition

[computational, thermodynamics] Specification of the derivatives of a function at a boundary of the vector domain, introduced by CARL NEUMANN (1832–1925). In thermodynamic applications, this defines the first order derivative conditions for the differential equation $f'' + f = 0$ over the interval $[x_1, x_2]$ as $f'(x_1) = \mathcal{A}_1$

and $f'(\mathbf{x}_2) = A_2$, where A_1 and A_2 are real numbers, or multidimensionally $\nabla^2 f + f = 0$, where ∇^2 is the Laplace operator, with on the boundary of the vector space $[\partial f(\vec{x})]/\partial \vec{n} = \varphi(\vec{x})$, with $\varphi(\vec{x})$ being a SCALAR function and $\vec{n}$ the normal to the boundary. In comparison, the Cauchy boundary condition is a combination of the Neumann boundary condition and the Dirichlet conditions and forms a mixed boundary condition.

Neumann function

[computational] Cylinder function of the second kind $N_p(x) = \lim_{k \rightarrow p} (J_k(x) \cos(k\pi) - J_{-k}(x)) / \sin(k\pi)$, where $J_k(x)$ and $J_{-k}(x)$ are BESSEL FUNCTIONS, named after CARL NEUMANN (1832–1925). The asymptotic value for large x yields $N_p(x) \approx \sqrt{2/\pi x} \sin(x - (p\pi/2) - (\pi/4))$. A special occasion is the radial equation, an specifically the Bessel equation of order ℓ yielding $\{ \rho^2(d^2/d\rho^2) + 2\rho(d/d\rho) + [\rho^2 - \ell(\ell+1)] \} f_\ell$, using $U_\ell(\rho) = \rho f_\ell(\rho)$. Solution to the Bessel equation of order ℓ (which is, for instance, an EIGENFUNCTION for the HYDROGEN ATOM $-(d^2/d\rho^2) + [\ell(\ell+1)/\rho^2] U_\ell(\rho) = U_\ell(\rho)$, with $U_\ell(\rho) = U_\ell(k\rho)$, k the wave-number), with Neumann solution: $N_p(x)$ (also see GREEN'S FUNCTION).

Neumann series

[computational] Analytical series developed by CARL NEUMANN (1832–1925) in 1877 defined as $\sum_{n=0}^{\infty} \mathbb{T}^n = (Id - \mathbb{T})^{-1}$, where $\mathbb{T}$ is an operator and Id and identity operator. Where the sum has analogies to the special case geometric series: $x/(1-x) = 1 + x + x^2 + \dots$. The identity operator, in the vector space X , defines the asymptotic behavior of the operator. The Neumann series has special implication for potential theory.

Neural network

[computational] Artificial network of information processing that is mirrored after how the biological nervous system processes information. The processing resembles cluster computer system, in a manner that processing ELEMENTS work in parallel to solve one specific complex problem. The artificial neural network learns as it processes, mimicking adjusting synaptic connections in the brain. The concept of neural networks predates the introduction of the personal computer. The first rudimentary artificial NEURON was produced by the neurophysiologist and analyst Warren McCulloch (1898–1969) and the logician and cognitive psychologist Walter Harry Pitts (1923–1969) in 1943. The neural network's learning aspect is represented as follows: the network adapts as follows: change the weight of an input by an amount proportional to the difference between the desired output and the actual output: $w_i = \eta * (D - Y) \cdot I_i$, where w_i is the weight of the "decision"/conclusion, η is the learning rate, I_i is the perception/input, D is the desired output, and Y is the actual output. This is referred to as the "perceptron learning rule" and was introduced in the early 1960s. Still, the learning process of the brain is mostly unknown; however, the basic operations by means of neurons, synapses, axons, and dendrites is anatomically described in great detail. In the biological neural network, there is a threshold that needs to be exceeded before a pulse is sent over the dendrites, leading to the cell NUCLEUS, before passing on to the axon that splits in a multitude of branches, causing a form of SIGNAL amplification by number of branches, which is subsequently passed on by SYNAPSE that communicates with the next network of dendrites and so on. A special neural network introduced by John Joseph Hopfield (1933–) in 1982 uses a similar recurrent artificial neural network, called an "associative

neural network.” The associative network of John Hopfield relies on content-addressable memory systems that are equipped with binary threshold nodes (see [Figure N.20](#)).

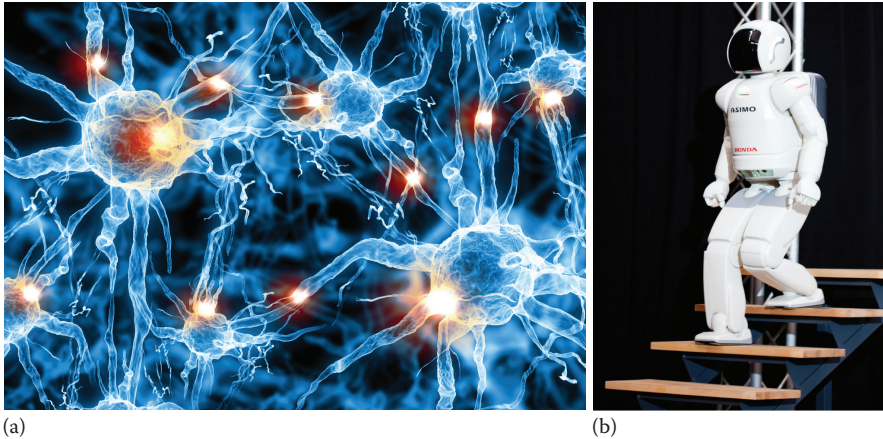


Figure N.20 (a) Advanced form of a neural network, adaption in the signal transmission, artist impression (b) robot “Asimo” developed by Honda relying on neural network.

Neuron

[biomedical, computational] Conducting and/or excitable CELL that propagates impulses based on membrane **DEPOLARIZATION** in binary format as pulse trains. Neurons are part of the nervous system, consisting of the autonomic and parasympathetic nervous system in the spine and diffusely distributed through the body of biological beings (animals and human), the brain and the senses (**HEARING**, smell, taste, touch, and **VISION** [sight]). Specialized neurons are found for muscular **ACTIVITY** and specific senses; they are referred to as the **MOTOR neuron** and sensory neuron, respectively, partially based on the specific chemical release from the **SYNAPSE**. Neurons are components of myelinated and nonmyelinated nerve cells, each conducting in respective fashion. **MYELINATED NERVE** cell are not excitable over the entire length, but only a certain point: the nodes of Ranvier. Nonmyelinated nerve cells can be excited at will at any location. The propagation process for the respective types of nerve cells is very different, the nonmyelinated neuron conducts continuously and the **MEMBRANE** depolarization propagation can be described by the **TELEGRAPH EQUATION** with respect to the **SIGNAL** transmission. The myelinated neuron depolarizes in jolts at the nodes of Ranvier, while the signal jumps without conduction, and propagates at least an order of **MAGNITUDE** faster than for the non-myelinated neuron (*see* **NERVE**) (see [Figure N.21](#)).

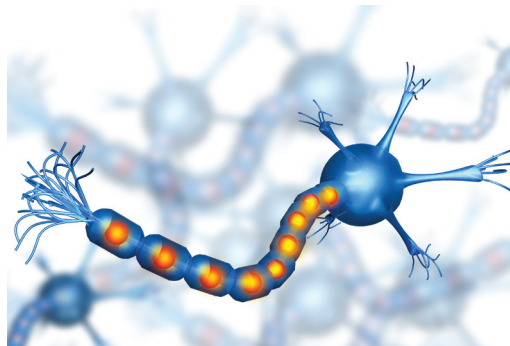
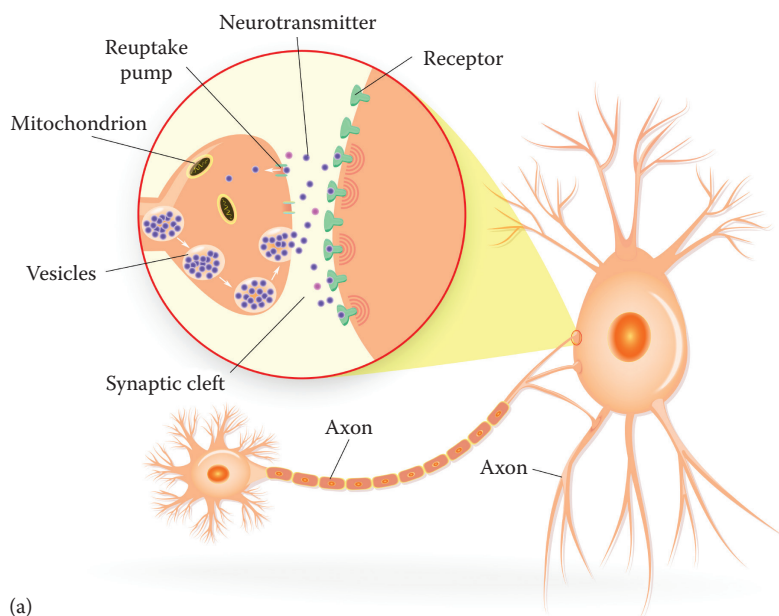


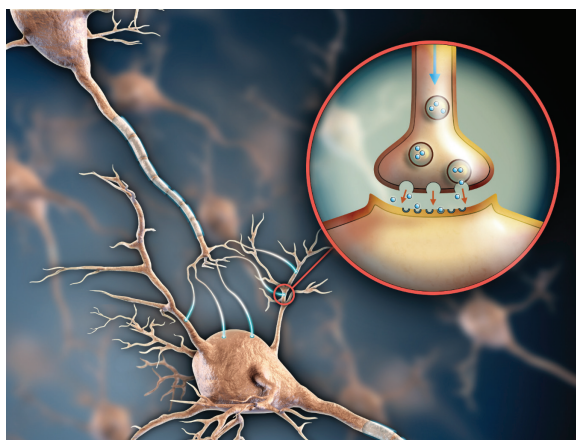
Figure N.21 Illustration of myelinated neuron.

Neurotransmitters

[biomedical, chemical, energy] Secretion of signaling molecules from the synaptic terminals of neurons (*see NERVE*) (*see* [Figure N.22](#)).



(a)



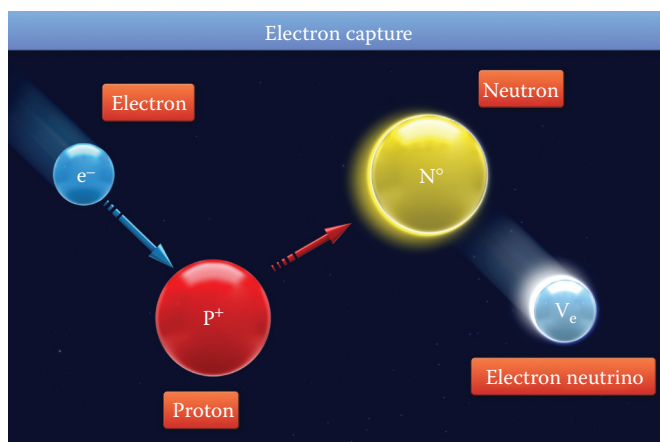
(b)

Figure N.22 (a,b) Typical structure of a chemical synapse in neural communications using neurotransmitter for signal relay between two or more nerve cells.

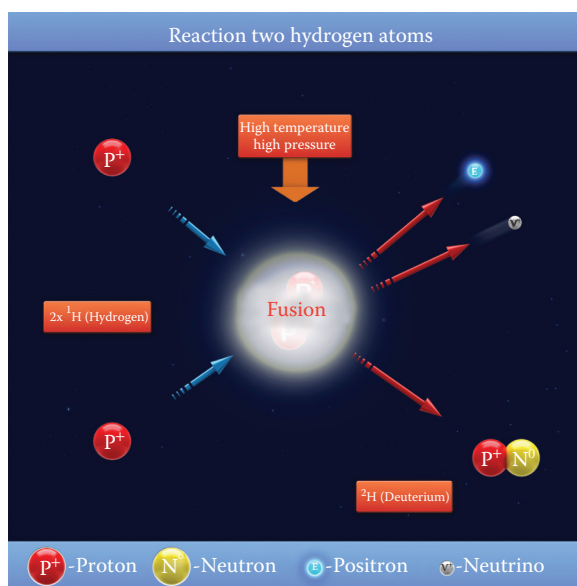
Neutrino

[atomic, general, high-energy, nuclear, quantum, solid-state] (ν^*), elementary PARTICLE with no CHARGE and negligible REST MASS compared to an electron is produced from the breakdown of a NEUTRON which balances its ENERGY (i.e., CONSERVATION OF ENERGY) with that of the emitted ELECTRON: $n \rightarrow p + e + \nu^*$, where n is a neutron, p is a PROTON, and e is an electron. In addition, the neutrino has a role in the CONSERVATION OF

MOMENTUM, SPIN, AND MASS. The electron and neutrino balance each other in such a way that when the electron ENERGY (i.e., KINETIC ENERGY) is high the neutrino energy is low and vice versa. The neutrino has an intrinsic ANGULAR MOMENTUM of $L = \hbar/2$, with $\hbar = h/2\pi$ the reduced PLANCK'S CONSTANT. The neutrino spins around the axis parallel to the direction of its MOTION. The rotational direction of the neutrino SPIN (clockwise/counterclockwise) is given by the RIGHT-HAND RULE. The neutrino has a counter part: the ANTI-NEUTRINO, which has the opposite spin given by the LEFT-HAND RULE (see Figure N.23).



(a)



(b)

Figure N.23 (a,b) Elementary neutrino release in the formation of deuterium resulting from a collision of two hydrogen atoms under high temperature and high pressure.

Neutrino (ν)

[atomic] Elementary PARTICLE released in the dissociation of a PROTON in a NEUTRON, a positron, and a neutrino: $\text{proton} \rightarrow \text{neutron} + \beta^+ + \nu$. Introduced by WOLFGANG PAULI (1900–1958) in 1931 and named in 1934 by ENRICO FERMI (1901–1954) and experimentally verified in 1959 by Clyde Cowan (1919–1974) and FREDERICK REINES (1918–1998). Neutrinos are very similar to the electron; however, they do not carry an ELECTRIC CHARGE, and it has an anti-particle (anti-neutrino: $\bar{\nu}$) (see [Figure N.24](#)).

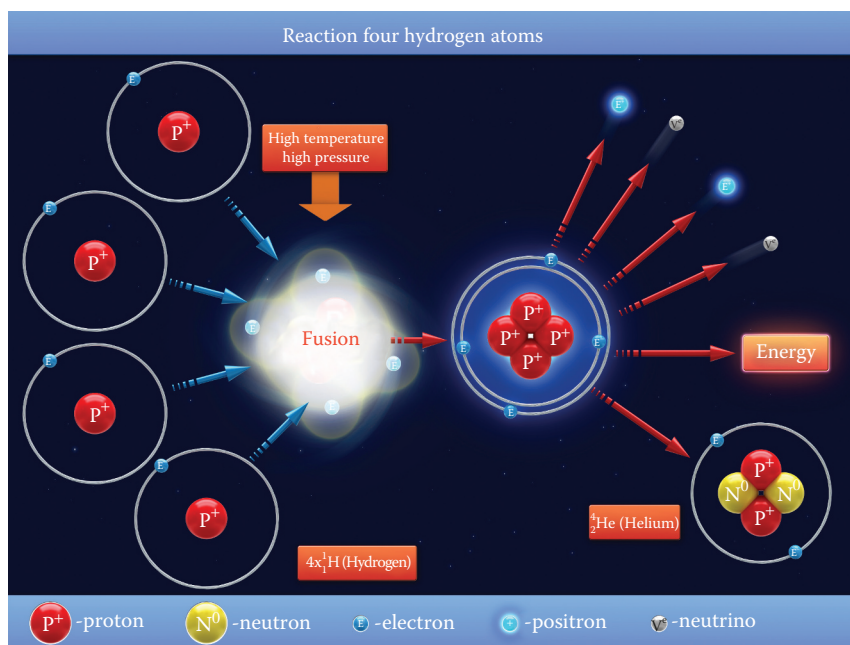


Figure N.24 The release of a neutrino during a fusion process involving four hydrogen atoms.

Neutron

[atomic] Subatomic neutral (no net ELECTRIC CHARGE) particle of the hadron class. The neutron is generally part of the atomic NUCLEUS. The neutron was experimentally verified by JAMES CHADWICK (1891–1974) in 1932, because the newly discovered RADIATION could not be explained by gamma principles or alpha

particles. The neutron is composed of three quarks: one UP QUARK and two DOWN QUARKS. The MASS OF THE NEUTRON is marginally larger than the mass of the PROTON. The lifetime of the neutron outside of the atomic nucleus is only 885 s (see [Figure N.25](#)).

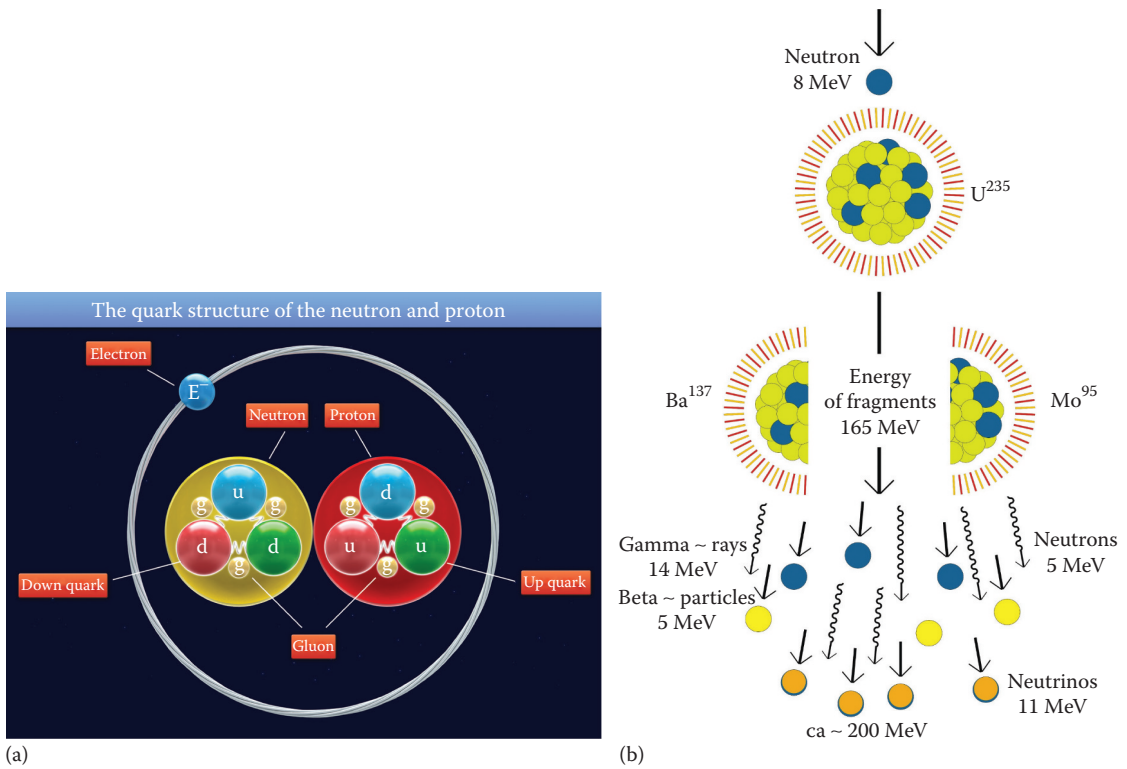


Figure N.25 (a,b) Neutrons involved in the uranium fission process.

Neutron cross section

[nuclear] Expression of the likelihood of a NUCLEON interaction, for a single collision the cross section of a neutron will depend on the PARTICLE involved in the interaction, size, charge and SPIN, and so on for nucleon-nucleon SCATTERING studies both experimental and theoretical information needs to be considered, specifically due to the Heisenberg uncertainty principles and WAVE functions involved. The cross section is a function of the “location” of the neutron (the NUCLEUS of the ELEMENT in question, type of nuclear reaction, the ENERGY (E) (including TEMPERATURE [T]), and the velocity (v) of both the incident particle and the nucleus with the imbedded neutron(s), as well as the relative ANGLE between the incident particle and the target nuclide. The standard unit for atomic, nuclear, and elementary particle cross section is the *barn* $= 10^{-28} \text{ m}^2$. The general cross section is the target area projection in the two-dimensional plane, perpendicular to the path of the incident PROJECTILE. The choice of “radius” is however not always that straightforward. One approximation would be the use of the Broglie wavelength of the neutron and the incident particle: $\lambda(E) = \hbar / \sqrt{2mE}$, where $\hbar = h/2\pi$ and $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is Planck’s constant. Subsequently, the cross section (σ) becomes proportional to a combination of the effective radius of the physical object (R) of the size combined with the MOTION: $\sigma(E) \propto \pi(R + \lambda(E))^2$. Frequently, cross

sections are provided in tables in reference books particular to the application (e.g., NUCLEAR FISSION and scattering) (also see CROSS SECTION) (see Figure N.26).

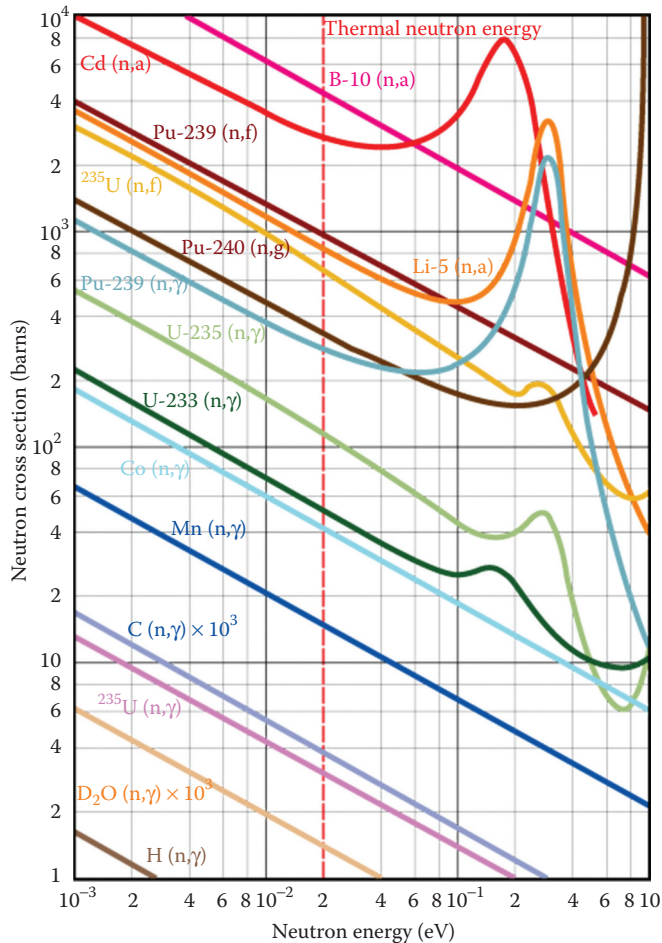


Figure N.26 Diagram of the relation between neutron cross section and neutron energy, image source: CC-BY-NC-SA—DoITPoMS, University of Cambridge (http://www.doitpoms.ac.uk/tlplib/nuclear_materials/).

Neutron detectors

[nuclear] Neutron can be detected by scintillation counters, BUBBLE-, or IONIZATION chambers and specialized semiconductor detectors, although the lack of charge presents specific limitations. Generally, neutron detectors can only detect fast NEUTRON and often require a nuclear conversion process generating a charged PARTICLE. Certain materials used for detection are boron, gadolinium, helium, and LITHIUM, connected to a photo-multiplier or photocell.

Neutron star

[astronomy/astrophysics, quantum] Compact STAR with diameter of approximately 20 km, presumably one of various mechanisms a star can terminate. As the star completes burning its nuclear fuel, it will terminate by means of a SUPERNOVA explosion. The neutron star is a condensed version of a star that originally had a mass four to eight times the mass of our Sun and concurrently has a gravitational attraction that is in the order of 2×10^{11} times the earth's GRAVITATIONAL ACCELERATION. Based on this neutron star's density a tablespoon of star MATTER would

weigh in excess of 2×10^9 kg. Because of the complex charge structure, neutron stars also may carry a MAGNETIC FIELD that is in the order of 10^6 times stronger than fields experienced on EARTH (see Figure N.27).

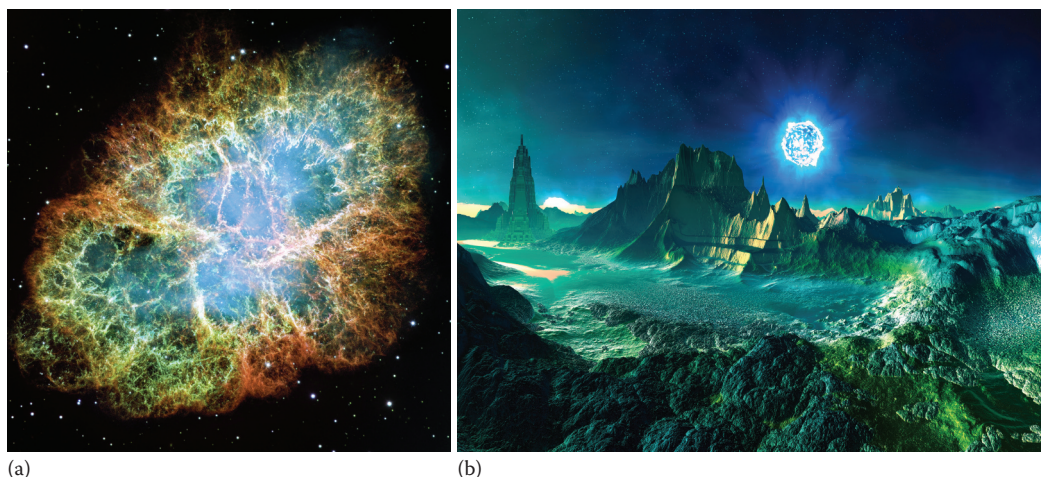


Figure N.27 (a) The core of the Crab Nebula is a strong pulsar neutron star; part of the constellation Taurus. (b) The Crab Nebula is a remnant of a supernova that exploded presumably in the year 1054 (date of origin derived from spectroscopic analysis).

Neutron–proton chart

[atomic, nuclear] Chart describing the transmutation of a NEUTRON to a PROTON for a specific atomic number ELEMENT: proton converts into a neutron, releasing both a POSITRON (β^+) and a NEUTRINO (ν): $\text{proton} \rightarrow \text{neutron} + \beta^+ + \nu$, obeying all CONSERVATION LAWS. Ultimately, heavy radioisotopes will DECAY until they attain the extreme stability of the iron NUCLEUS. Note that in IRON the nucleons are the most tightly bound of all nuclei. The chart lists the BINDING ENERGY per nucleon displayed as a function of the atomic mass number (amu).

Newcomen, Thomas (1664–1729)

[general, mechanics] An English blacksmith. He is the inventor of the atmospheric reciprocating steam ENGINE in collaboration or in parallel with the works of THOMAS SAVERY (1650–1715), DENIS PAPIN (1647–1712), and JOHN CALLEY (1663–1717) approximately in 1712 (see Figure N.28).



Figure N.28 Thomas Newcomen (1664–1729).

Newton, Isaac, Sir (1642–1727)

[fluid dynamics, general, mechanics, nuclear, solid-state] An English scientist supporting the corpuscular theory of light as proposed by the ancient Greek philosophers, also the pioneer of MECHANICS (i.e., DYNAMICS). Newton postulated three laws of motion (Newton's first, second, and third laws) and one law on GRAVITY (Newton's LAW OF UNIVERSAL GRAVITATION) that define the concepts of modern PHYSICS (nonrelativistic). NEWTON'S FIRST LAW describes that any object will remain at rest without an external perturbation or remains in constant MOTION; NEWTON'S SECOND LAW defines that an object will accelerate under the influence of a force; NEWTON'S THIRD LAW describes the equal and opposite force experienced (e.g., floor exerts a force). Sir Newton indicated, as one of the first, that SURFACE WAVES in liquids can be defined mathematically in his 1687 *Principia* (see Figure N.29).



(a)



(b)

Figure N.29 (a) Sir Isaac Newton (1642–1727) and (b) stamp with the “infamous” apple that supposedly struck Isaac Newton on the head to initiate his thought process regarding the formalization of the concept gravity.

Newton (N)

[general] Unit of force, expressed in International Standard System (SI), kgm/s^2 . The definition was introduced based on the Newtonian system, specifically $F = ma$, force F equals the mass m multiplied by the acceleration a of that mass.

Newton's equation of motion

[general, mechanics, thermodynamics] A system of n particles, each with mass m_ζ , with representative position vector $\vec{r}_\zeta$ for the ζ th particle, and momentum $\vec{p}_\zeta = m_\zeta(d\vec{r}_\zeta/dt)$ can be described with a force ($\vec{F} = m(d^2\vec{r}/dt^2)$) combining the external force on each respective particle ($\vec{F}_\zeta^{\text{ex}}$) and the internal interaction between the particles ($\vec{F}_{\zeta\zeta'}$) as $d\vec{p}_\zeta/dt = \vec{F}_\zeta^{\text{ex}} + \sum_{\zeta' \neq \zeta} \vec{F}_{\zeta\zeta'}$. The system is subject to all CONSERVATION LAWS, including but not limited to conservation of momentum, CONSERVATION OF MASS, and conservation of force, introduced by SIR ISAAC NEWTON (1642–1727).

Newton's first law

[biomedical, general, mechanics] A body at rest remains at rest and a body in MOTION tends to remain in uniform linear motion at constant velocity. It was introduced by SIR ISAAC NEWTON (1642–1727). This is also called the LAW OF INERTIA because the constant velocity defines constant INERTIA. Generally, this translates in the condition that when the sum of the forces on an object are zero the body is compelled to stay in

constant uniform linear velocity. The “first law” also defines the concept of INERTIAL REFERENCE FRAME; the inertial reference frame can be external to the object or it can be assigned to travel with the object.

Newton's law for fluids

[fluid dynamics, mechanics, thermodynamics] For a NEWTONIAN FLUID the equation of force (F) per unit VOLUME (V) of a FLUID is defined as $\vec{F}/V = (1/V)(d\vec{p}/dt) = (1/\rho)(D\vec{v}/Dt) = (1/\rho)(\partial\vec{v}/\partial t) + \rho\vec{v} \cdot \nabla\vec{v}$, where $\vec{p}$ is the momentum vector, t the time, ρ the density, and $\vec{v}$ the velocity of FLOW as a vector field; where D/Dt represents the “substantive derivative,” and $\nabla = (d/dx) + (d/dy) + (d/dz)$ the gradient. This was introduced by SIR ISAAC NEWTON (1642–1727).

Newton's law of cooling

[thermodynamics] The rate of change of the temperature of a body of material is directly proportional to the difference between the TEMPERATURE (T) of the object (T_b) and the ambient temperature (T_a): $dT/dt = k_{\text{temp}}(T_b - T_a)$, where k_{temp} is the rate of cooling, and t time (*also see* FOURIER'S (CONDUCTION) LAW AND FICK'S LAW). This was introduced by SIR ISAAC NEWTON (1642–1727).

Newton's law of viscosity

[biomedical] Constitutive equation (not a fundamental law though) that is used to define the MOTION of primarily Newtonian fluids, under a restricted range of conditions. This was introduced by SIR ISAAC NEWTON (1642–1727). Sometimes interpreted as the RESISTANCE to deformation of solids as the shear modulus, which is the ratio of the shear stress to the shear strain: $E_{\text{mod}} = (\text{shear-stress})/(\text{shear-strain})$, and in fluids, the ratio of the shear stress to the rate of shear is $\mu = (\text{shear-stress})/(\text{rate of shear-strain})$.

Newton's rings

[optics] Interference pattern resulting from a variable gap DISTANCE between two surfaces, specifically when a plano-convex LENS is placed on a flat window pane. The air-gap (separation: t) with distance increasing with respect to the center of the contact location provides a reflection pattern where the path length back-and-forth between the first and second surface has a difference of multiple odd number of half-wavelengths will result in amplification (*Note:* the PHASE of the WAVE changes at the REFLECTION from AIR to glass, although the GLASS to AIR reflection does not incur a phase change): $2t = (m + (1/2))\lambda$, where λ is the wavelength of the light. When the optical path length differs by a whole number of wavelengths, the INTERFERENCE will create amplification (see Figure N.30).

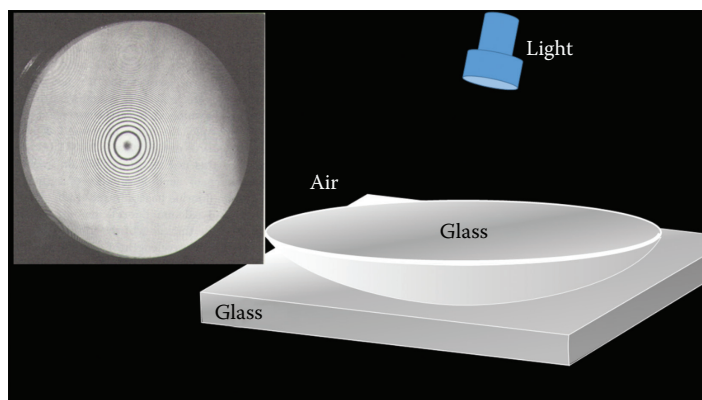


Figure N.30 How Newton's rings are formed.

Newton's second law

[biomedical, general, mechanics] Placed in an INERTIAL REFERENCE FRAME a body with mass m will accelerate (acceleration a) with a MAGNITUDE proportional to the applied net force (F), moving in the direction of the force: $\sum \vec{F} = m\vec{a}$. This was introduced by SIR ISAAC NEWTON (1642–1727).

Newton's third law

[biomedical] An object experiencing an external force from another body will in turn exert a force equal in MAGNITUDE but opposite in direction on said initial body, also called “law of reaction” or in popular science terminology: “for every action there is an equal but opposite reaction.” This was introduced by SIR ISAAC NEWTON (1642–1727).

Newtonian fluid

[biomedical, fluid dynamics] Medium with linear VISCOSITY response as a function of the velocity gradient within the FLOW, that passes through the origin of the rheogram outlining velocity-gradient versus shear stress. Examples of Newtonian fluids in approximation are water and gases, while in practicality, there are no real perfect Newtonian fluids; however, under certain conditions, they are a close approximation; for instance, water will have a non-Newtonian BOUNDARY LAYER at a rigid WALL. Certain fluids may transition over into a Newtonian behavior when a shear-rate threshold is exceeded. BLOOD can act as a Newtonian liquid in the center of large vessels, while at low flow and small vessel diameter, blood is a pseudoplastic fluid. In close relation to the Newtonian fluid is the Bingham fluid, which has an offset from the origin, a flow-initiation threshold at minimum shear stress, a concept introduced by SIR ISAAC NEWTON (1642–1727) (also see VISCOSITY) (see Figure N.31).

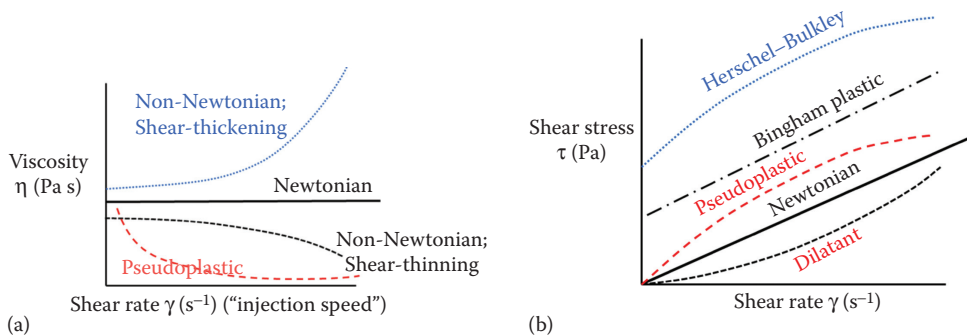


Figure N.31 (a,b) Graphical representations of the concept of Newtonian liquid, with perfectly linear viscosity.

Newton–Cotes methods

[computational] Quadrature rule used to interpret the trapezoidal rule and can be generalized to represent higher degree polynomial interpolants. A function $f(x)$ in the domain $\{a, b\}$ can be developed in a series of polynomials and can be integrated precisely with the help of the Newton–Cotes quadrature rule. The function is developed as $f(x) = \sum_{j=0}^n f(x_j) \ell_j(t)$, where $\ell_j(t) = \prod_{i=0, i \neq j}^n (t - x_i) / (x_j - x_i)$, with $j = 0, 1, \dots, n$ being the Lagrange polynomial, where all data points are given nodes within the domain. The accuracy has a degree of at least n and the integral $\int_a^b f(t) dt$ is solved numerically. Newton number ($Ne = F_{\text{drag}} / \rho_f v^2 \ell^2$), dimensionless number representing the ratio of resistive (hydrodynamic DRAG $F_{\text{drag}} = m\ell/t^2$) to the net INERTIA force, where ρ_f is the density of the FLUID, v is the characteristic velocity, L is the characteristic length, m is the mass, and t is the characteristic time.

Newtonian mechanics

[general] Under nonrelativistic conditions MECHANICS has a straightforward correlation between space and time. Newtonian mechanics describes the classical mechanics of MOTION with all CONSERVATION LAWS intact as well as the three laws of Newton apply. These are concepts related to the work of SIR ISAAC NEWTON (1642–1727).

Newtonian reflecting telescope

[general, optics] Optical device designed by SIR ISAAC NEWTON (1642–1727) that relies on REFLECTION of light combined with REFRACTION of light to avoid the DISPERSION and CHROMATIC ABERRATION obtained from diffracting optical ELEMENTS (e.g., PRISM and lens) (see [Figure N.32](#)).



Figure N.32 Newtonian reflector telescope.

Newtonian theory of gravity

[general] See LAW OF UNIVERSAL GRAVITATION.

Nicholson, John Williams (1881–1955)

[astrophysics/astronomy, computational, general] A mathematician and astronomer from the United Kingdom/Great Britain who obtained astronomical SPECTROSCOPY and based on the observations of certain nebulae, in particular the CRAB NEBULA, proposed the existence of several ELEMENTS in 1911 that were at the time still undiscovered. However, his hypothesis was somewhat unfounded and the proposed “proto-elements” were never confirmed. The unconventional methods and bad results from Nicholson were however the lead for several confirmed discoveries and theoretical derivations on spectral line patterns.

Nier, Alfred Otto Carl (1911–1994)

[astrophysics/astronomy, atomic, nuclear] A physicist from the United States, and a pioneer in mass-spectroscopy device development and experimental observation. Nier designed the mass spectrometers used on the MARS space travel by Viking spaceships, in a miniaturized form (see [Figure N.33](#)).



Figure N.33 Alfred Otto Carl Nier (1911–1994) in 1940. (Courtesy of Elmer Anderson Library of the University of Minnesota, Minnesota, Minneapolis, MN.)

Niobium

[acoustics] Chemical ELEMENT, metal: $^{41}_{93}\text{Nb}$, formerly known as columbium. Niobium is widely used in superconducting alloys, which may also contain TITANIUM and tin. Specifically found in superconducting magnets used in MRI scanners.

Nipkow, Paul Gottlieb (1860–1940)

[general, nuclear] An engineer from Poland/Germany (Prussian Empire). He is the discoverer of the principle of television transmission in 1884 (see [Figure N.34](#)).



Figure N.34 Paul Gottlieb Nipkow (1860–1940) in 1884.

Nipkow disk

[general, nuclear] Spiral perforated disk used to display a sequence of images imbedded in a perforated disk that is illuminated by a lamp for projection on a wall designed by PAUL GOTTLIEB NIPKOW (1860–1940) in 1884. The concept of the Nipkow disk was used in 1928 by Scottish (Great Britain) engineer John Logie Baird (1888–1946) at the Baird Television Company based on the, by then, expired Nipkow patent in “emchanica” television transmission. The Nipkow disks were a popular pass-time for handheld IMAGE sequence viewing. Predating the Nipkow disk is the phenakistoscope (or “spindle viewer”), introduced in 1832 by physicist Joseph Antoine Ferdinand Plateau (1801–1883) from Belgium in collaboration with his sons. Coincidentally and independently, a similar device was introduced in the same year by Simon Ritter von Stampfer (1792–1864) from Austria, who had named his invention a stroboscope and the zoetrope (also named Daedaleum) by William George Horner (1786–1837) from Great Britain introduced in 1834. Prior to Plateau, MICHAEL FARADAY (1791–1867) and Peter Mark Roget (1779–1869) had designed a device called the “Michael Faraday’s Wheel,” consisting of two discs spinning in opposite directions. Even farther back, there is documented evidence that EUCLID (~300 BC) also described the same or similar concepts (see [Figure N.35](#)).

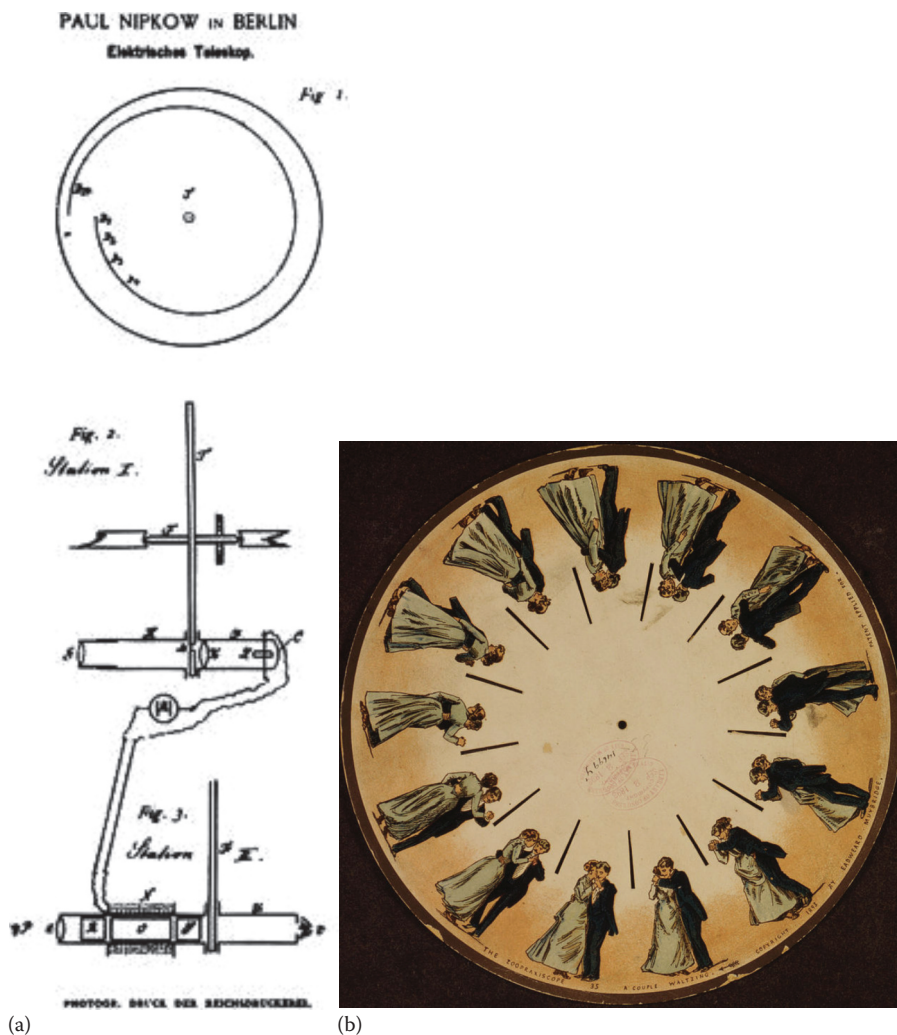


Figure N.35 (a) Nipkow disk patent application 1884 and (b) phenakistoscope disk by Eadweard Muybridge (1830–1904) in 1893.

Nitinol

[biomedical, solid-state] Metal alloy of equal portions of nickel and TITANIUM. Metallic compound that is sensitive to thermal stress and strain, providing a mechanism for flexible but sturdy structural support due to the difference in RESISTANCE to longitudinal and lateral strain. Nitinol alloys have the following unique properties: shape memory (return to the original shape after applying a specific elevated temperature) and superelasticity (10–30 times the ELASTICITY of the original metallic components). One specific application of nitinol is in vascular stents, to enlarge the vascular lumen under atherosclerosis, implemented under balloon angioplasty (see [Figure N.36](#)).



Figure N.36 (a,b) Nitinol stent concept used to expand the vessel lumen. (c) Nitinol stent maintains a flexible and wide pipe diameter.

Nitrocellulose

[biomedical, solid-state] Highly flammable mixture of nitric esters made by nitrating CELLULOSE. The nitrating process is mediated through exposure under nitric ACID or other nitrating agents. It is originally known as guncotton (because of its cotton-like POLYMER appearance), the main ingredient in gun powder. Nitrocellulose was used historically as an explosive (starter) or propellant. Additional applications are found as plasticizer in recording film strip (e.g., PHOTOGRAPHY and film), introduced by Kodak in 1889 (see [Figure N.37](#)).

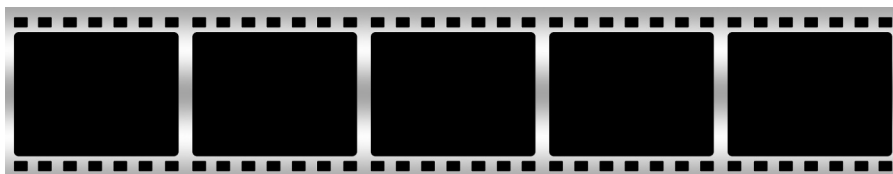


Figure N.37 Strip of photographic film negatives on Nitrocellulose base.

Nitrogen (N₂)

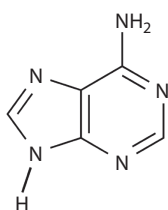
[biomedical, general, geophysics, thermodynamics] Chemical ELEMENT, diatomic MOLECULE, gaseous under standard conditions: $^{14}_7\text{N}$, MELTING POINT: $-210^\circ\text{C} = 63\text{K}$. Nitrogen is the main component of the Earth's ATMOSPHERE, at approximately 78% of the total balance of gases. It was discovered by Daniel Rutherford (1749–1819) in 1772. Nitrogen is very versatile and is essential in the following: fertilizers, ammonia (NH₃), “super-glue” (cyanoacrylate), is part of Kevlar fabric, and is found in amino acids; it is also crucial component in nitroglycerin as an explosive LIQUID, which is additionally used as vasodilator (i.e., the chemical interaction will make the vessel WALL extend by releasing the muscular constraint in the medial layer in the

vessel wall and smooth MUSCLE, increasing the BLOOD flow) medication for HEART problems and other vascular concerns (*see* N¹⁴) (*see* Figure N.38).

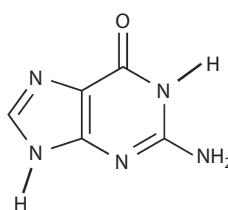


(a)

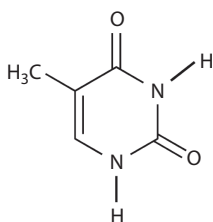
Nitrogenous bases



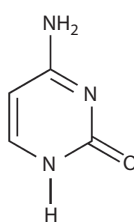
Adenine



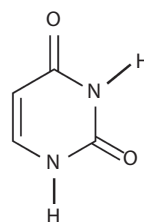
Guanine



Thymine



Cytosine



Uracil

(b)

Figure N.38 (a) Nitrogen is used for rapid cooling and maintaining at low temperature and (b) nitrogen used in chemical compounds; examples of nitrogen bonds in DNA constituents.

Noble gas

[atomic, general] Monatomic ELEMENTS that were originally considered to be inert due to the OXIDATION number of zero (0). The six noble gases, all in group 18 (VIIIa) of the PERIODIC TABLE OF ELEMENTS are as follows: helium, neon, argon, krypton, xenon, and radon, all odorless and colorless with minimal chemical reactivity. In the 1960s, there were new discoveries that indicated the potential for chemical links with noble gases; in 1962, the first CHEMICAL COMPOUND of a noble gas was uncovered: xenon hexafluoroplatinate, by Neil Bartlett (1932–2008), and more thereafter. In the outer shell, all noble gases have the

maximum number of electrons allowed: two for Helium, and eight for all the remaining five elements, which is what makes these elements so stable. The term is an English translation from the German word “Edelgas,” introduced by Hugo Erdmann (1862–1910) in 1898 (see Figure N.39).

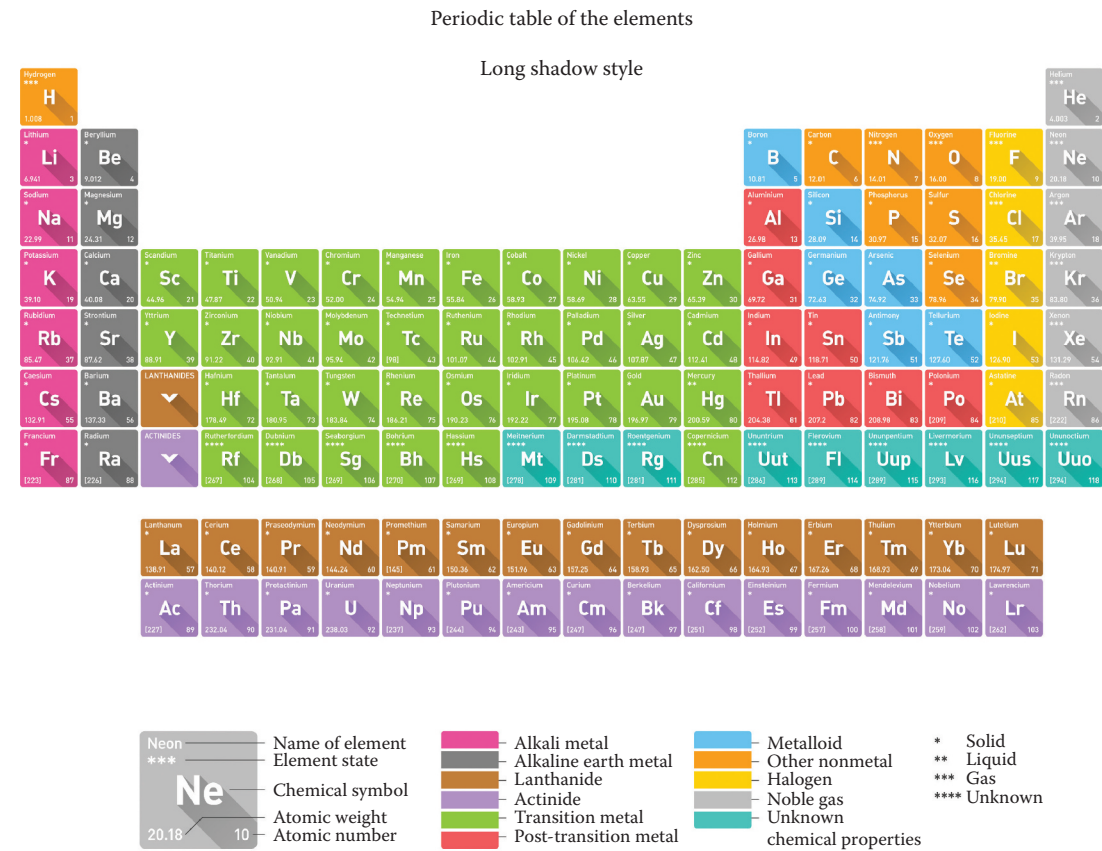


Figure N.39 Periodic table of elements highlighting the Noble gases in light green.

Nodal precession

[mechanics] Orbital precession of the rotation axis of a PLANET or moon. This phenomenon is responsible of the climatological changes on EARTH where the northern and southern hemispheres alternate in proximity to the Sun over the span of the conveniently chosen timescale of 1 year. The earth’s MOON has two precession motions: the first along the long axis precesses “eastward” just under 9 years (presumably caused by the solar “tide”), whereas the second precession is the orientation of lunar orbit inclination, which is the track along which the plane of the earth’s orbit intersects with the moon’s orbit. The first precession

pertains to the respective line of the apsides: perigee and apogee. The second, turning of the lunar orbit, has a period of approximately 18.6 years (see [Figure N.40](#)).

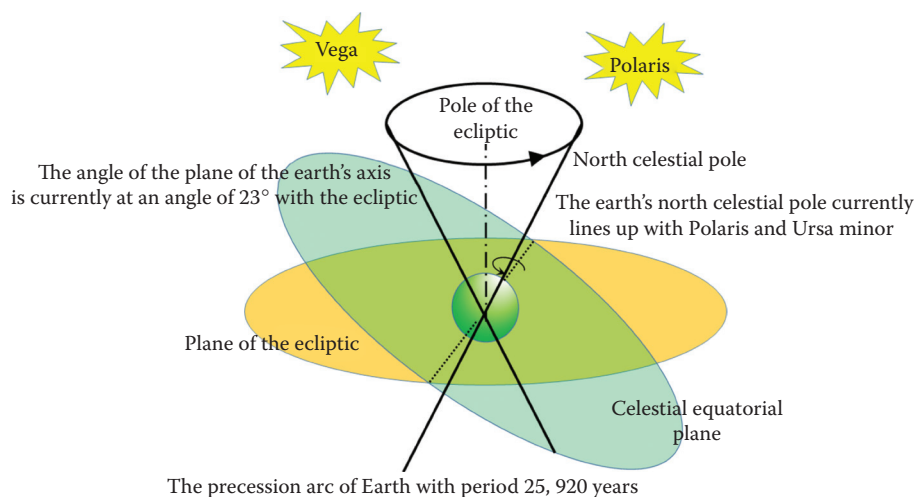


Figure N.40 Nodal precession.

Noddack, Ida Eva (1896–1978) (maiden name: Ida Eva Tacke)

[energy, general] A scientist from Germany. In 1935, Ida Tacke published the first work on the concept of ENERGY generation by NUCLEAR FISSION, while in 1925, she and her team uncovered two missing ELEMENTS in Mendelev's periodic table of elements; ELEMENT 75: rhenium and element 43: masurium (rejected by the scientific community for unknown reasons, and later attributed to Carlo Perrier (1886–1948) and EMILIO GINO SEGRE (1905–1989) as technetium, current name). Her discoveries were based on spectroscopic X-RAY using the equation from the work by HENRY GWYN JEFFREYS MOSELEY (1887–1915) for identification: $\nu = (3/4)R_y(Z-1)^2$, where ν represents the frequency, $R_y = 10973731.6 \text{ m}^{-1}$ is the RYDBERG CONSTANT, and Z is the atomic number (see [Figure N.41](#)).



Figure N.41 Ida Eva Noddack (maiden name: Ida Eva Tacke) (1896–1978).

Node of Ranvier

[biomedical, electromagnetism] Ionically permeable section in the WALL of MYELINATED NERVE cells between impermeable isolated segments, wrapped by Schwann cells. This anatomical phenomenon was described by the French histologist Louis Antoine Ranvier (1835–1922). The amount of ION exchange during DEPOLARIZATION is substantially less at the node of Ranvier than for a full length membrane depolarization under nonmyelinated nerve-cell activation pulse propagation, in the order of 200 times less. The reduced ion exchange provides one of the advantages in pulse propagation, next to the fact that a depolarization pulse “jumps” from node to node, instead of based on priming of the neighboring wall segment for nonmyelinated cells. Myelinated nerve cells propagation is at least an order of MAGNITUDE greater (see NERVE and MYELIN) (see [Figure N.42](#)).

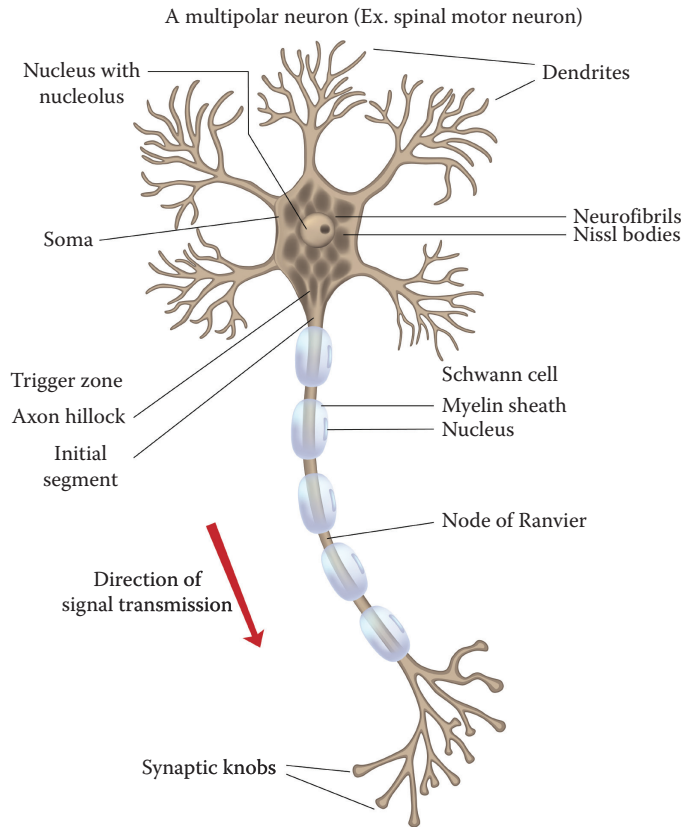


Figure N.42 Node of Ranvier.

Noether, Amalie (Emmy) (1882–1935)

[computational, general] A mathematician and scientist from the Prussian Empire, Germany. The work of Amalie Noether involved the definition of the following three concepts: associative law (mathematical grouping can be interchanged, in rudimentary format: $(a + b) + c = a + (b + c)$ and $(a * b) * c = a * (b * c)$), commutative law (finding association between phenomena and functions characterized by substitution, interchange, or exchange: $a + b = b + a$ and $a * b = b * a$), and the distributive law (captured in essence as $a * ((b + c) = (a * b) + (a * c))$). Her work was far reaching and influential and she was commended by ALBERT EINSTEIN (1879–1955) for her mathematical contributions to his efforts. Noether created a theorem that

united the symmetry in nature and the universal laws of conservation: Noether's theorem, or NOETHER'S PRINCIPLE. Her mathematical efforts were influential in the uncovering of the HIGGS BOSON (see [Figure N.43](#)).



Figure N.43 Amalie (Emmy) Noether (1882–1935).

Noether's principle

[computational, energy, general, thermodynamics] For every conservation law, there is a continuous symmetry and alternatively for every continuous system, there is a symmetry that correlates to a corresponding conservation law. It was introduced by AMALIE NOETHER (1882–1935), also known as “Noether's theorem.”

Noise

[acoustics, general, optics, theoretical] Random fluctuations in the AMPLITUDE and/or frequency pattern resulting from characteristics of the phenomenon, such as temperature, external forces, external RADIATION, as well as other changing boundary conditions such as perturbation of reflective/SCATTERING media. Additional noise factors may come from the fact that the sensing mechanism used for QUANTIFICATION of the phenomena (providing the “SIGNAL”) is not able to remain in one single location. In certain cases, the measurements on an active system, biological or physical, will have changes in chemical equilibrium and chemical constituents

due to METABOLIC ACTIVITY (biological) or due to forced or passive DIFFUSION. The changes in chemical configuration can influence the accuracy of the measurement of another event/phenomenon due to the electrical interaction with the device or the wired or wireless communications of these observations. One significant noise factor in measurements on various levels are solar flares, which may even interact with the semiconductor materials used in a device. Acoustic noise can change the FREQUENCY SPECTRUM as, for instance, resulting from dust on a vinyl recording album played over STEREO equipment for reproduction of the authentic event. Optical noise can result from density changes as well as from thermal collisions and thermal emissions. Measurement of the brain's activities by electroencephalogram electrodes on the SKIN can be influenced by MOTION or sweat, and other MUSCLE activity such as EYE motion, as well as MACHINES switching in neighboring rooms (creating inductive INTERFERENCE). An indication of the stability of an event, measurement, phenomenon, or equipment is usually indicated by the signal-to-noise ratio, the higher the better. Noise in FLOW systems can result from unexpected TURBULENCE (see Figure N.44).

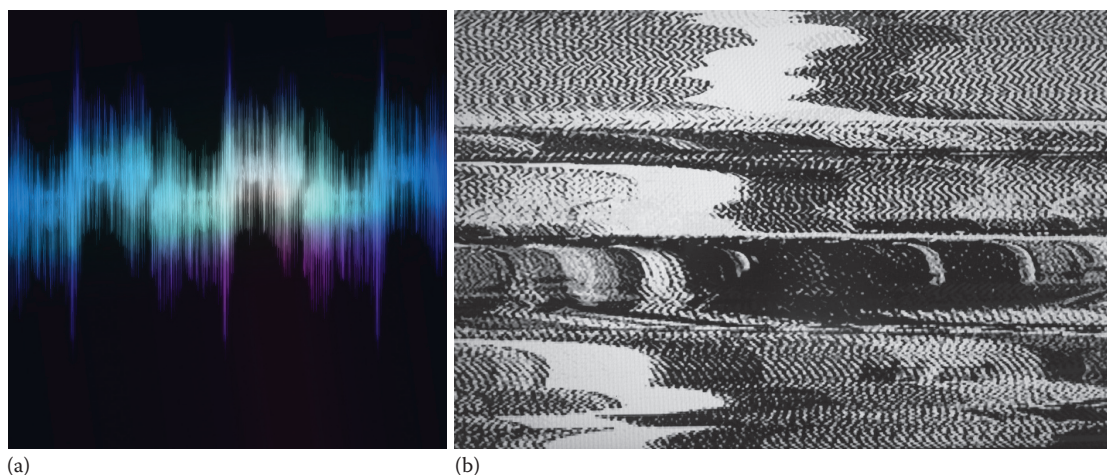


Figure N.44 (a,b) Television image distorted by electronic noise resulting from the interference in the line of transmission (primarily affecting analog signal only), or thermal effects in the processing electronics. During analog signal transmission moving conductive objects will reflect the signal stream of electromagnetic radiation, which in turn will also be captured by the antenna of the receiving instrument. Old-fashioned “rabbit-ear” antennas sitting on top of the television were notorious for interference noise, either induced by people walking through the room or a plane passing over the volume of air where the electromagnetic television wave transmission passed from transmitter to receiver station.

Nollet, Jean-Antoine (Abbé) (1700–1770)

[energy] A physicist from France. Nollet is most known for his invention of a device to measure (static) ELECTRIC CHARGE the ELECTROSCOPE. His work involved the use of the LEYDEN JAR as well, electrifying a group of 180 soldiers on display for King Louis XV. Abbé Nollet also phenomenologically described the phenomenon that the sharper an object, the greater the charge stream, that is, the electric field is a function of the radius of curvature of a CONDUCTOR in his attempts to describe the rudimentary principles of FLOW of electric MATTER and forces between electrically charged bodies in 1745, predating the fundamental work of his fellow countryman CHARLES AUGUSTIN DE COULOMB (1736–1806). His work coincided with the efforts of the American statesman and scientist BENJAMIN FRANKLIN (1706–1790), demonstrating LIGHTNING as a form of ELECTRICITY. Additional work of Jean-Antoine Nollet provided insight in the concepts of OSMOSIS,

illustrating how a SOLVENT passed selectively through a MEMBRANE, providing the foundation for the work by JACOBUS HENRICUS VAN'T HOFF (1852–1911) (see [Figure N.45](#)).



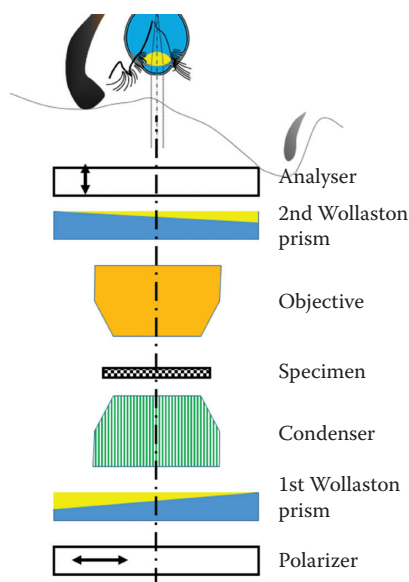
Figure N.45 Jean-Antoine (Abbé) Nollet (1700–1770).

Nomarski, Georges (Jerzy) (1919–1997)

[optics] An optical scientist and theoretician from Poland. Nomarski developed a special INTERFERENCE microscope, the “differential interference contrast (DIC) microscope,” using polarized light that is split in two perpendicularly POLARIZATION directions for enhanced contrast, split and recombined by an optical configuration of two Wollaston prisms. The Nomarski MICROSCOPE is a special form of PHASE contrast microscopy (see [Figure N.46](#)).



(a)



(b)

Figure N.46 (a) Georges (Jerzy) Nomarski (1919–1997) and (b) diagram of the differential interference contrast (DIC) microscope.

Nomenclature for nuclear reactions

[nuclear] A form of shorthand for the process of a nuclear reaction. For instance, the interaction of nitrogen with a NEUTRON forming radioactive carbon and PROTON in the Earth's ATMOSPHERE under cosmic radiation as ${}_0^1n + {}_7^{14}\text{N} \rightarrow {}_6^{14}\text{C} + {}_1^1p + \text{energy}$, or in "shorthand": ${}^{14}\text{N}(n, p){}^{14}\text{C}$ ("transfer reaction"), where the first item in brackets refers to the PROJECTILE. Note that ${}^{14}\text{C}$ can be used for radioactive dating, due to its integral incorporation in all biological media. The nomenclature for the interaction process has the following classifications: compound reaction, direct reaction, INELASTIC SCATTERING, knock-out reaction, nuclear photoeffect, nuclear scattering, RADIATIVE CAPTURE, resonance reaction, RUTHERFORD SCATTERING, and transfer reaction.

Nonadiabatic process

[atomic, solid-state, thermodynamics] A process in theoretical chemistry that involves the interaction in a molecule that hold the exchange between electronic and nuclear vibrational MOTION, referred to as "vibronic coupling." Vibronic coupling pertains to the MIXING of electronic states of the MOLECULE as a result of small vibrations and is tied to the derivative of the WAVE function for the configuration. Nonadiabatic chemical processes occur at the conical intersections. In a molecular ENERGY configuration when two potential energy surfaces are degenerate and intersect the energy state in conical intersect. At this point the nonadiabatic coupling between these two energy states is also nonvanishing. The energetic BOUNDARY LAYER surrounding the conical intersect no longer obeys the BORN–OPPENHEIMER APPROXIMATION, supporting the nonadiabatic conditions. Nonadiabatic effects, specifically involve the splitting and SCATTERING of the wave packet (QUANTUM effect dominated solution to the time-dependent SCHRÖDINGER EQUATION) at potential energy surface crossings, such as associated with TUNNELING. Chemical interactions that can be described by the conical intersection are photoelectric reactions, combustion, and explosion, for instance. One specific example of the conical intersect is the stability of DNA (DNA molecule encoded with a range of biological properties: genetic structure) under irradiation by ULTRAVIOLET light, where the "excited" electrovibrational state of the molecular wave packet will "roll-back" to the electronic GROUND STATE on the conically curve potential energy surface of the molecular binding. The number of vibrational DEGREES OF FREEDOM is directly related to the number of atoms making up the molecule; for instance, a diatomic molecule has two degrees and consequently progressively upward. On a nuclear level, similar principles will apply; only in this case, the energy potentials are outlined by the PROTON and neutron interactions (see Figure N.47).

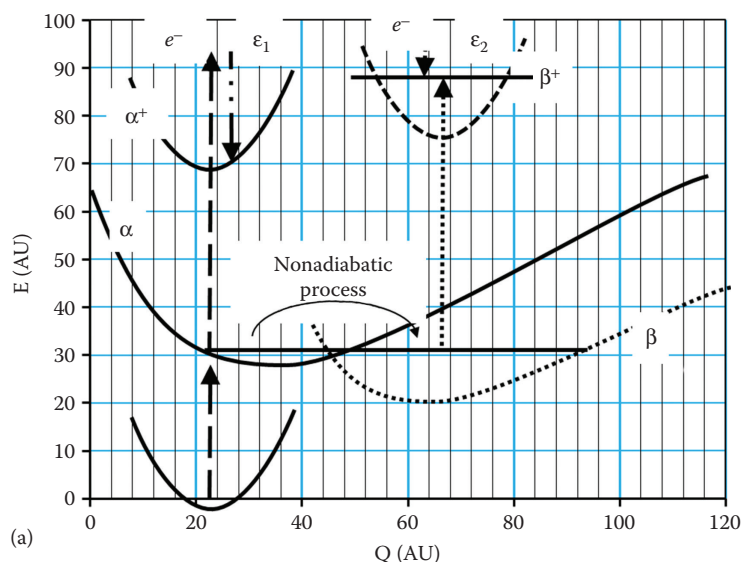


Figure N.47 Nonadiabatic processes occur on electronic and macroscopic scale: (a) nuclear vibration energy diagram. (Continued)

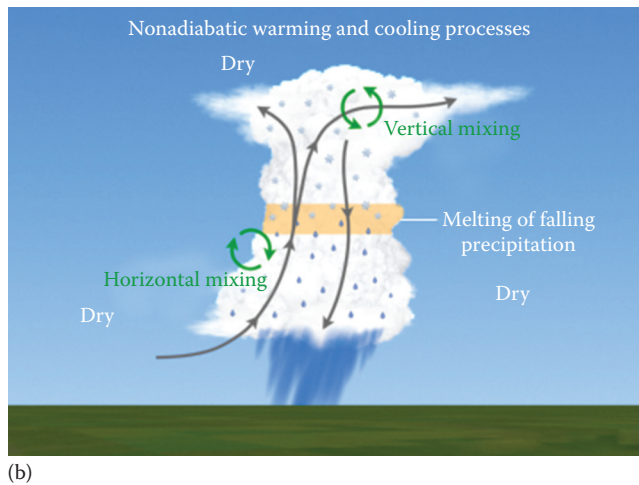


Figure N.47 (Continued) Nonadiabatic processes occur on electronic and macroscopic scale: (b) atmospheric nonadiabatic thermal inversion.

Nonconductor

[general] See INSULATOR.

Nondegenerate ground-energy value

[quantum, thermodynamics] Ground state of a quantum-mechanical energy system. A quantum MECHANICAL ENERGY level is said to be degenerate if two or more different measurable states exist simultaneously, where the number of corresponding states indicates the degree of DEGENERACY for a specific energy level. This is represented by a single EIGENVALUE solution for the Hamiltonian of several independent eigenstates. For a nondegenerate state, the condition is that the eigenvalue in its eigenspace is one dimensional. By definition, the GROUND STATE is the only energy state that can be nondegenerate, because there is no change in conditions at this energy, but this not exclude degenerate ground states from occurring. Theoretically, this can be illustrated by the density functional theory, which provides the electronic structure of atoms, molecules, and solids in their ground states. The electronic density distribution plays a central role, defining the degenerate ground states, SPIN density (describing spin-up and spin-down densities as well as PARAMAGNETISM or cooperative MAGNETISM), as well as multicomponent systems (e.g., nuclei and electron–hole assemblies in semiconductor).

Nondimensional groups

[computational, fluid dynamics, thermodynamics] Dimensionless analysis is a mathematical technique used to determine the relationships between several variables and hence predict physical parameters that influence the fluid FLOW, HEAT TRANSFER, and other transfer process. By converging to the basic MLT units (kg, m, s), the elementary concepts become dimensionless. The LAW OF SIMILARITY allows the principles to be applied in analogy between FLUID DYNAMICS, THERMODYNAMICS, or various other aspects of engineering and physics. Examples of dimensionless parameters are the REYNOLDS NUMBER, Froude number, Weber number, and MACH NUMBER.

Nondispersive component

[biomedical, solid-state] The free ENERGY at the interface surface of a medium with another medium. The nondispersive free energy is the geometric mean of the free energy of medium 1 (for instance, a solid) and medium 2 (for instance, a LIQUID). The free energy can, for instance, be derived from Fowkes' expression and the Young's equation for the respective medium.

Nondispersive wave

[acoustics, mechanics, optics] Wave propagation in a nondispersive medium, with no inherent deformation. DISPERSION stands for the variability in propagation velocity with respect to direction of propagation, governed by the WAVE EQUATION in one dimensional: $(\partial^2 \chi(x, t) / \partial t^2) - v^2 (\partial^2 \chi(x, t) / \partial x^2) = 0$, or multidimensional: $\partial^2 \tilde{\chi} / \partial t^2 - v^2 \nabla^2 \tilde{\chi} = 0$ for a wave phenomenon χ with (PHASE) velocity of propagation v , where the velocity is independent of the wavelength. The wave equation is generally solved by SEPARATION OF VARIABLES, taking the real part $\chi(x, t) = \text{Re}[\tilde{\chi}(x) * t(t)]$. Nondispersive waves maintain both the spectral and temporal information (see [Figure N.48](#)).

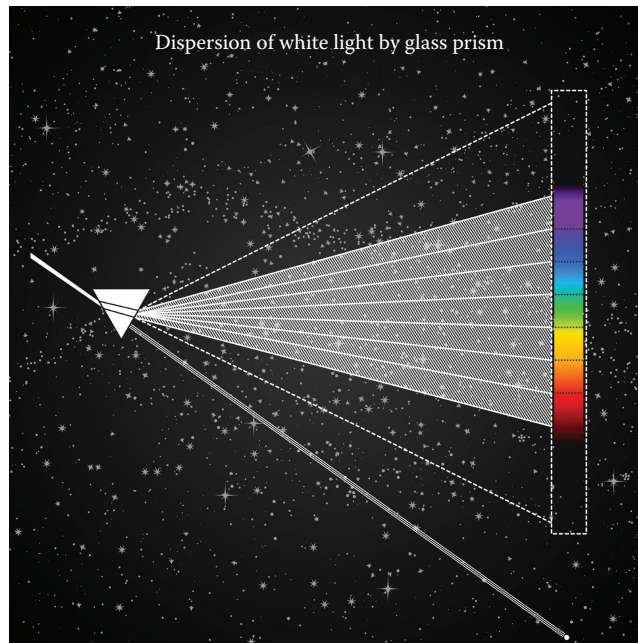


Figure N.48 A nondispersive wave can be generated by a single wavelength emitter, such as a laser; in contrast to broad band emitters which will be subject to dispersion at certain gradients or discontinuities with the medium of transmission. Dispersion of white light from a prism. In contrast a laser beam can hold its coherence for light years, spanning across the galaxy, as used in remote sensing, collecting the returning signal from great distances with embedded encoding that can be resolved by interferometric analysis. Certain mechanical waves can be nondispersive, under well-defined boundary conditions, for instance, in a perfectly homogeneous medium (free-space [atmospheric], at uniform temperature and pressure) or single wavelength acoustical sensing.

Nonelastic

[biomedical, mechanics, nuclear] Rigid material that will have a yield strength at which it will break without deformation. In nuclear collision, the nonelastic CROSS SECTION refers to the steady-state target cross section of nuclides solely based on the physical size and interactions with inherent loss of kinetic ENERGY (i.e., inelastic) (see COMPTON SCATTER) (see Figure N.49).

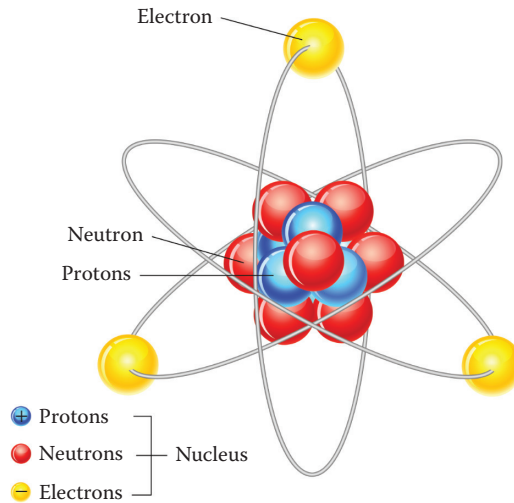


Figure N.49 Rigid, nonelastic hard-shell model of the atom, specifically the nucleus.

Nonequilibrium state

[thermodynamics] The broad range of conditions defining chemical reactions and transport processes (e.g., ENERGY and material).

Nonideal mixture

[thermodynamics] Mixture composed of components that do not behave as an IDEAL GAS or operate at PHASE transitions. According to the ideal GAS LAW, the pressure of the constituents of a mixture should change linearly with temperature and volume, assuming a fixed quantity. In parallel, for liquids, an ideal liquid obeys RAOULT'S LAW, linking the VAPOR PRESSURE to the individual contributions of the respective components. For liquids, the PHASE DIAGRAM of nonideal mixtures introduces the concept of an azeotropic mixture. In an azeotropic mixture, the vapor state has the exact same composition as the LIQUID state, so that the components cannot be extracted by simple DISTILLATION.

Non-Newtonian fluids

[fluid dynamics] Every fluid, the NEWTONIAN FLUID is a theoretical idealistic condition, specifically pertaining to the VISCOSITY aspects (see NEWTONIAN FLUID and VISCOSITY).

Nonohmic electrical devices

[general] Devices that do not obey OHM'S LAW: $V = IR$, where the voltage drop (V) is directly linked to the CURRENT (I) through a RESISTANCE (R). Example of a nonohmic device is a doped silicon DIODE; the voltage current diagram is not linear, but has a logarithmic correlation and specifically, the resistance is

not a constant. For a DIODE, the resistance is generally different for the direction of current, sometimes by orders of MAGNITUDE.

Nonpolar nature of a medium

[biomedical, chemical, fluid dynamics, mechanics, thermodynamics] Materials (especially liquids) can on a molecular level be electronically inert with neutral charge across the MOLECULE. Oil is a clear example of the natural nonpolarity. Water is a polar liquid. Detergents have a polar and a nonpolar side to the molecule, making them ideal for acting as a degreaser while dissolved in water.

Nonrelativistic energy

[nuclear] Even for nuclear events, a range of ENERGY can be identified for which a nonrelativistic approach will yield only a small error, in the order of 1%. This generally applies to ALPHA DECAY, which is nonrelativistic for the momentum; however, beta DECAY is relativistic for the momentum. On the energy level, electrons operate nonrelativistically when $KE < 20.7$ keV, and for protons, the phenomena can be treated nonrelativistic when $KE < 38$ MeV (*also see ENERGY*). The nonrelativistic prediction of the DIRAC EQUATION for the nonrelativistic coulomb problem has the following expression, using a SCALAR potential resulting from the NUCLEUS ($\phi = A_0$): $((\vec{p}^2/2m) - (Ze^2/4\pi r) - (\vec{p}^4/8m^3c^2) + (Ze^2\{\vec{L} \cdot \vec{S}\}/8\pi m^2c^2r^3) + (Ze^2\hbar^2/8m^2c^2)\delta^3(\vec{r}))\Psi = E^{nr}\Psi$, where $E^{nr} = E - mc^2$ is the nonrelativistic energy, $\vec{p} = m\vec{v}$ is the momentum, m is the mass of the PARTICLE, v is the velocity, Z is the charge number, $e = 1.60217657 \times 10^{-19}$ C is the coulomb charge, r is the separation DISTANCE, $\vec{L}$ is the ORBITAL ANGULAR MOMENTUM, $\vec{S}$ is the spin, $c = 2.99792458 \times 10^8$ m/s is the speed of light, $Ze\delta^3(\vec{r}) = \nabla \cdot \vec{E}$, $\hbar = h/2\pi$ with $h = 6.62606957 \times 10^{-34}$ m²kg/s Planck's constant, and Ψ the "Schrödinger" wavefunction. The phenomena are determined by the fact that nonrelativistic particles have continuous and discrete DEGREES OF FREEDOM (with respect to momentum, for instance, as a continuous reference frame and SPIN component for the discrete reference frame).

N

Normal compressive strain (ϵ_{nc})

[general, mechanics] Strain of an object under compression, in contrast to TENSILE STRAIN, but no difference in expression (*see NORMAL STRAIN*) (*see Figure N.50*).



Figure N.50 Vice applying normal compressive strain.

Normal distribution

[atomic, computational] Probability density function for events and measured values: $f_{\text{normal}}(x) = 1/(\sigma_{\text{stat}}\sqrt{2\pi})\exp[-(1/2\sigma_{\text{stat}}^2)(x - \mu_{\text{stat}})^2]$; where μ_{stat} is the mean value of the observation x and σ_{stat} is the statistical variance. Generally, the variance can be derived as follows:

$\sigma_{\text{stat}}^2 = 1/(n-1) \sum_{i=1}^n (x_i - \mu_{\text{stat}})^2$, with n values. This is closely linked to the GAUSSIAN DISTRIBUTION. The standard normal distribution has as conditions $\sigma_{\text{stat}}^2 = 1$ and $\mu_{\text{stat}} = 0$ (see Figure N.51).

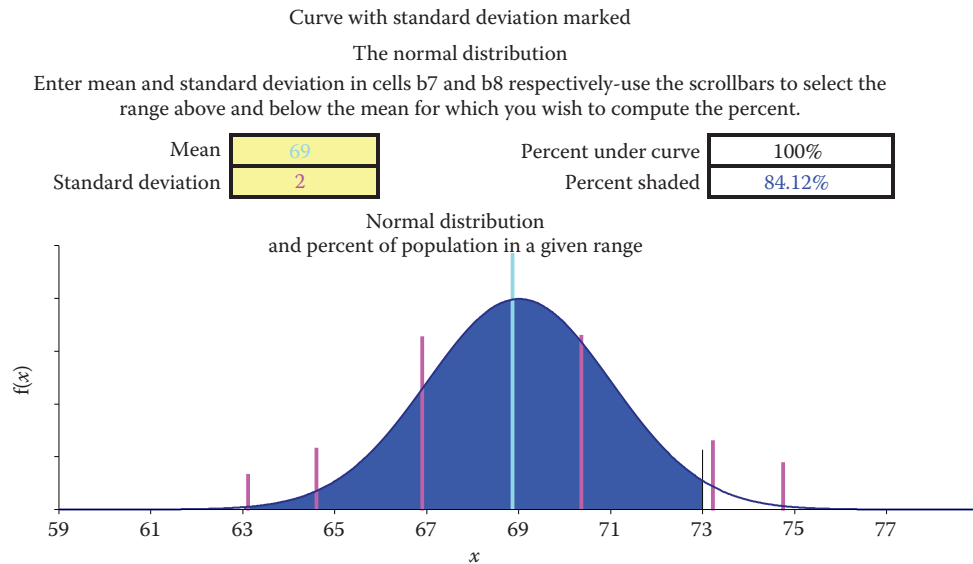


Figure N.51 Plot of the normal distribution, plotting the function $f(x)$ as a function of a variable “ x ” around the center point “69”.

Normal force (F_n)

[biomedical, general, mechanics] Resiprocating force in response to an applied force, normal to the surface; perpendicular to the surface. The force of a table top in response to a object resting on the table yields the normal force in equivalence to NEWTON’S THIRD LAW. Friction is a direct function of the normal force: $f_K = \mu_K F_n$, where μ_K represents the KINETIC FRICTION coefficient for kinetic friction force f_K (see Figure N.52).

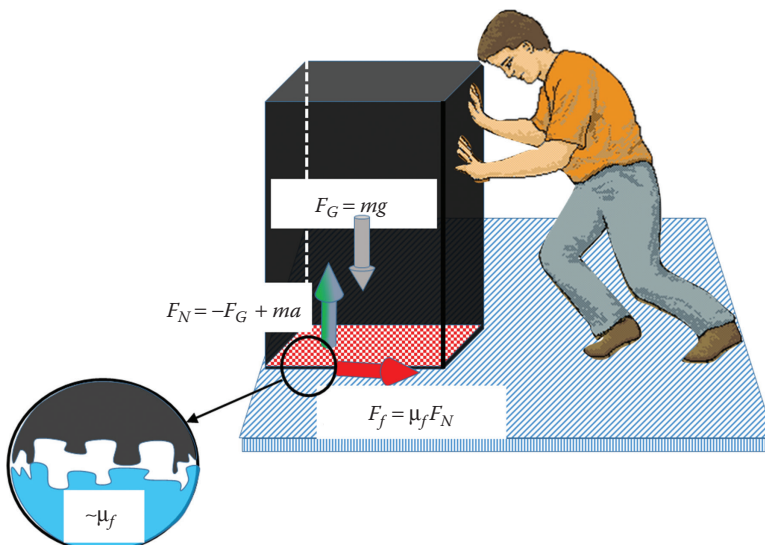


Figure N.52 Normal force.

Normal strain (ϵ_n)

[biomedical, mechanics] Fractional change in body length (ℓ) as a result of an applied normal STRESS: $\epsilon_n = \Delta\ell/\ell$, a rod under tension is under TENSILE STRAIN while a rod under compression is under compressive strain (see Figure N.53).

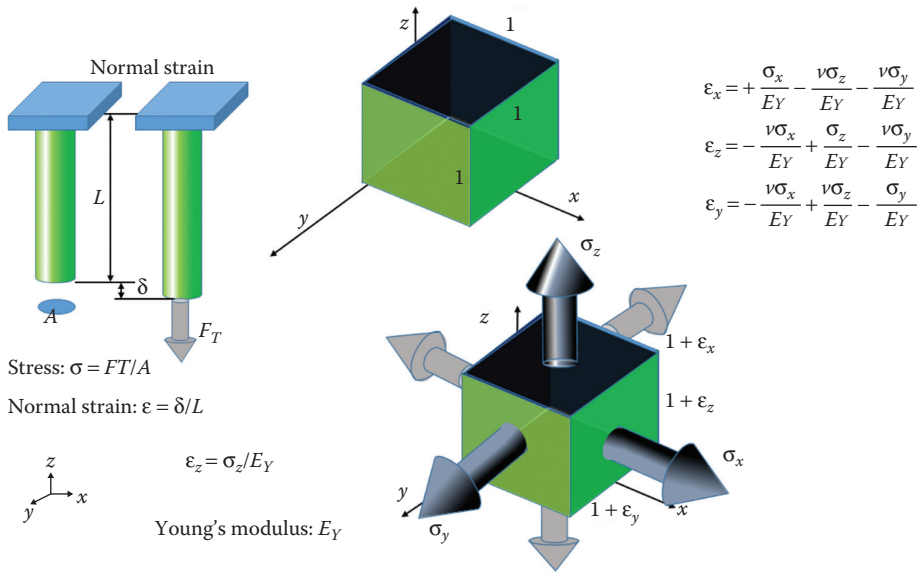


Figure N.53 Normal strain.

Normal stress (σ_n)

[biomedical, mechanics] Ratio of normal force (F_n) applied on a body and in the cross-sectional area (A) the applied force is normal to $\sigma_n = F_n/A$, when the body is under tensile force the stress is considered TENSILE STRESS, and alternatively under compression compressive stress. The difference between pressure and stress is in the fact that pressure is a SCALAR quantity and stress is a TENSOR (see Figure N.54).

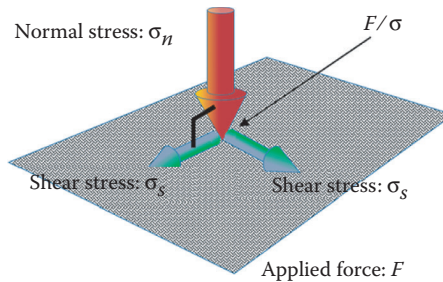


Figure N.54 Normal stress.

Normal Zeeman effect

[atomic, nuclear, quantum] See ZEEMAN EFFECT, NORMAL.

Normalization

[atomic, computational, general] Process of unification of the combined results by incorporation of a coefficient that renders a peak of the PROBABILITY distribution of an event or the range of data to unity.

Norman, Robert (1550–1600)

[general] A seaman and maritime scientist from Great Britain who invented the concept of navigation by means of a magnetic compass in 1581, describing the LODESTONE (also found as “loadstone,” a MAGNET) and ensuing practical applications to navigation. Note that the magnetic properties were known to the ancient Greek, well before the introduction in seafaring navigation. Robert Norman discovered the fact that the compass needle is influenced by the fact that the earth’s MAGNETIC FIELD does not run parallel to the earth’s surface, causing a deviation called “magnetic inclination.” The MAGNETIC inclination is the ANGLE that the magnetic field makes with the horizontal as a function of the LATITUDE (see [Figure N.55](#)).

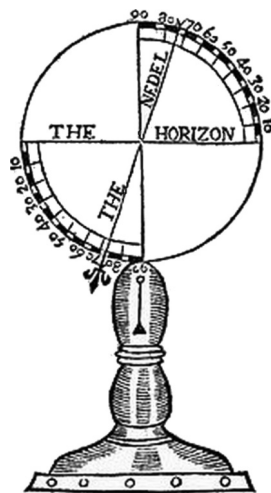


Figure N.55 Magnetic dip as outlined and described by Robert Norman (1550–1600).

North

[electromagnetism, general, geophysics] Colloquial reference to the direction indicated by the compass needle. (see **MAGNETIC NORTH POLE**). In **MAGNETIC** devices, this indicates the location of the device where the **MAGNETIC FIELD** lines emerge to loop around in three-dimensional space to terminate on the South Pole of the device (see [Figure N.56](#)).



(a)



(b)

Figure N.56 (a) A compass pointing north and (b) ice-field found at the north-pole. There is no lands at the north pole, in contrast to the land found at the south-pole.

North geographic pole

[general] See **GEOGRAPHIC NORTH POLE**.

North magnetic pole

[general] See **MAGNETIC NORTH POLE**.

Northern Light

[astrophysics, atomic, energy, geophysics] See *AURORA* and *AURORA BOREALIS*.

Nozzle

[fluid dynamics, mechanics, thermodynamics] A duct with a variable CROSS SECTION. Because of the change in the cross-sectional area (A) as a function of location in the FLOW of a fluid, the flow can be regulated and directed, achieving, under certain conditions, acceleration and forming a high-velocity (v) stream. The FLUID velocity distribution can be explained by the principles of CONSERVATION OF MASS (m), more specifically for an INCOMPRESSIBLE FLUID: $dm/dt = \rho v A$. A nozzle converts potential ENERGY confined by the work performed under PV , where P is the pressure and V the volume, into kinetic energy. Nozzle provides flow that is nearly adiabatic and result in little or no change in potential energy and require no shaft to convey the work. The change in ENTHALPY (H) across the nozzle is $\Delta H = (v_0^2 - v_1^2)/2g$, where v_0 is the exit flow velocity, v_1 is the flow velocity before the nozzle, and g is the GRAVITATIONAL ACCELERATION. The throat is the narrow section of the nozzle, after which it may expand or not. Under certain conditions, the outflow from the nozzle may reach Mach conditions, specifically when: $P_0/P_1 \cong (1 + 0.2Ma_c^2)^{-3.5}$, where P_1 is the pressure in the reservoir leading to the nozzle, P_0 is the external pressure, and Ma_c is the MACH NUMBER on exit from the nozzle. The maximum flow rate is achieved when the velocity in the throat, with cross section A_t reaches sonic speed, providing: $(dm/dt)_{\max} = 0.0404(p_1/\sqrt{T_1})A_t$, where T_1 is the ABSOLUTE TEMPERATURE in the reservoir. The ISENTROPIC efficiency of a nozzle, if defined by the difference between the actual velocity (v_a) and the isentropic velocity (v_{is} , presumed constant ENTROPY [S]) on exit is $\eta_{\text{nozzle, is}} = (v_{a,0}^2/2g)/(v_{is,0}^2/2g) = v_{a,0}^2/v_{is,0}^2$, where the isentropic velocity follows from the entropy (S) versus enthalpy (H) diagram for the flow. The adiabatic efficiency is defined as $\eta_{\text{nozzle, adiabatic}} = (H_{is,0} - H_{is,1})/(H_{a,0} - H_{is,1})$. ADIABATIC COMPRESSION is exemplified by TEMPERATURE (T) versus entropy (S) diagram, respectively enthalpy (H) versus entropy (S) diagrams (see Figure N.57).

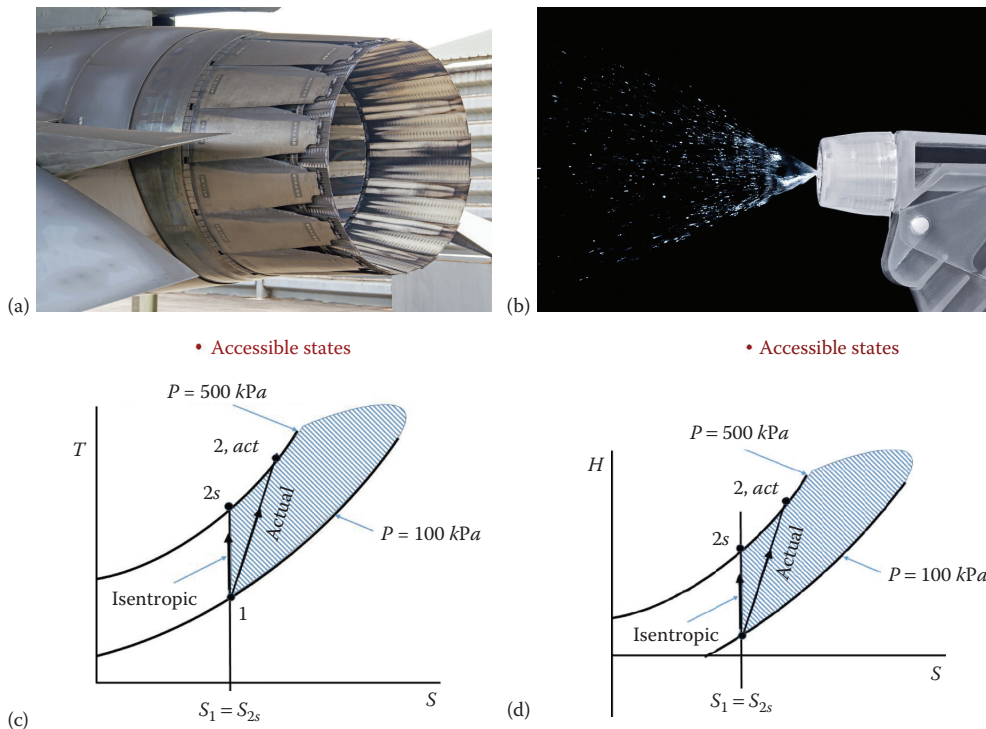


Figure N.57 (a) Jet engine nozzle, (b) adiabatic compression at the nozzle described by a TS phase diagram, (c) HS diagram, and (d) TS diagram for adiabatic compression processes.

npn transistor

[electronics, general] Standard design semiconductor TRANSISTOR that has a P-TYPE SEMICONDUCTOR (electron deficit, holes) material sandwiched between two electronegative semiconductor materials, with excess electrons (predominantly silicon or germanium). The segments of the npn transistor are collector, base, and emitter, in sequence of current FLOW, where the base is controlled by an externally applied electrical potential and regulates the current flow from the collector to emitter. The current flow is regulated by the Fermi levels at the respective *pn*-junctions for the lightly doped collector and heavily doped emitter. The lesser used PNP TRANSISTOR is the alternative (see [Figure N.58](#)).

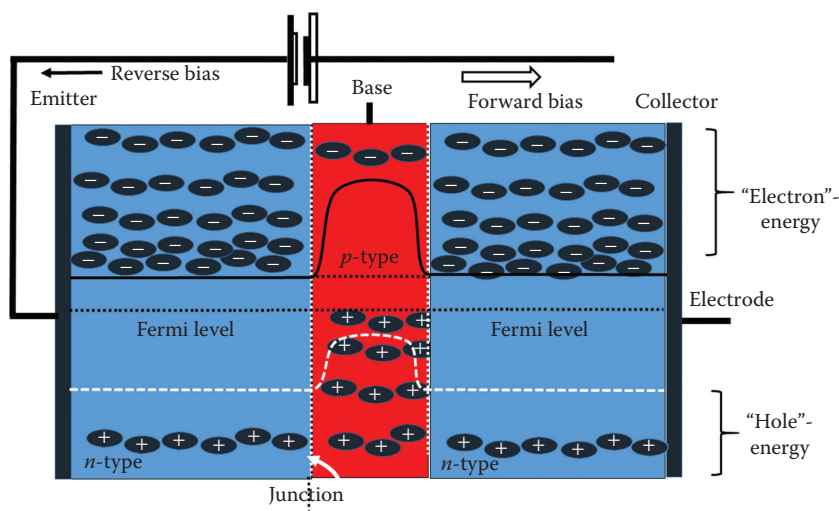


Figure N.58 Transistor, functional diagram.

NSOM

[optics] See NEARFIELD SCANNING OPTICAL MICROSCOPE.

n-type doping

[atomic, electronics, general] The process of administering an excess amount negative ions in a semiconductor matrix. The process changes the ENERGY BANDS (e.g., FERMI LEVEL) of the medium, in particular at the boundary with a *p*-type doped medium in a DIODE or TRANSISTOR configuration (*also see pn-JUNCTION*) (see Figure N.59).

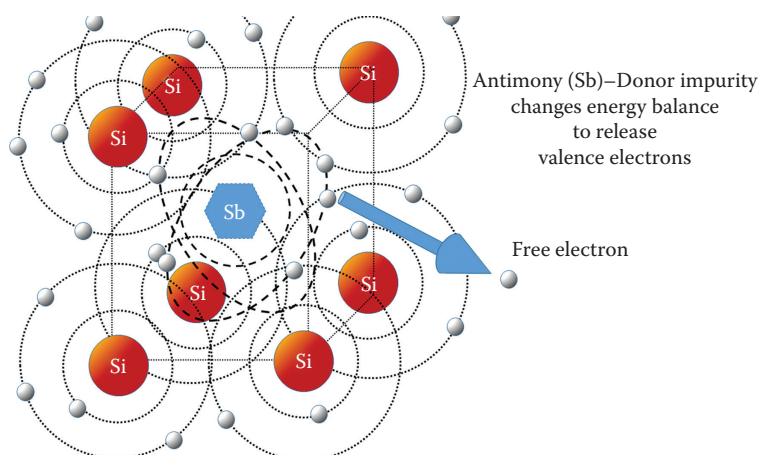


Figure N.59 N-type semiconductor, doped with antimony as electron-donor.

n-type semiconductor

[electronics, general] Electronegative semiconductor materials, with excess electrons (base predominantly silicon or germanium) achieved by DOPING with phosphorus (P), arsenic (As), or antimony (Sb) (*see pn-JUNCTION, npn TRANSISTOR, and SEMICONDUCTOR*).

Nuclear adiabatic (de-)magnetization

[atomic, nuclear] A procedure that is used to change the temperature of a system by changing the local absolute value of the MAGNETIC FIELD strength. This process was discovered independently by both PETER DEBYE (1884–1966) in 1926 and William Francis Giaque (1895–1982) in 1927. The nuclear ADIABATIC DEMAGNETIZATION provided a tool to lower the temperature well in the decimal numbers below 1 K near the ABSOLUTE ZERO. In this situation, the mechanism of action relies on the existence of some form of disorder that can be organized by configuring MAGNETIC DIPOLE seeds. The magnetization M of a medium results from circulating electric (eddy) currents on a MACROSCOPIC scale or on an atomic level by elementary atomic magnetic moments. Magnetization is defined as the magnetic moment per unit volume of these collective currents or moments. The units are gauss in the electromagnetic system of units (emu) and weber per square meter in the mks system, respectively: $1 \text{ (weber/m}^2\text{)} = (1/4\pi)10^4 \text{ gauss}$.

Nuclear angular momentum

[nuclear] See ANGULAR MOMENTUM, SPIN.

Nuclear atom

[general] Atomic model developed in 1911 by ERNEST RUTHERFORD (1871–1937) based on a small NUCLEUS with POSITIVE CHARGE surrounded by an orbiting cloud of electrons. This model is primarily based on phenomenological observations and data and was a marked improvement on the “plum pudding model” introduced in 1904 by JOSEPH JOHN THOMSON (1856–1940), of whom Rutherford was a student.

This is different from the Bohr model, which has more theoretical and far-reaching implications. The Rutherford model was based on the scattering CROSS SECTION of a thin sheet of METAL (e.g., gold) bombarded by alpha particles. The RUTHERFORD SCATTERING cross section for the nuclear atom is as follows: $d\sigma_{\text{Ruth}}/d\Omega = \left(Z_1 Z_2 e^2 / 8\pi\epsilon_0 m v_0^2 \right)^2 \csc^4(\theta/2)$, where σ_{Ruth} is the SCATTERING cross section as a function of the SOLID ANGLE OF PERCEPTION Ω for a target with charge number Z_2 and incident ballistic charge number Z_1 for electron charge $e = 1.60217657 \times 10^{-19} \text{ C}$ and ballistic mass m , measured with angle θ under PROJECTILE velocity v_0 , with ϵ_0 being the permittivity of free space (see Figure N.60).

Structure of the atom
Rutherford atomic model

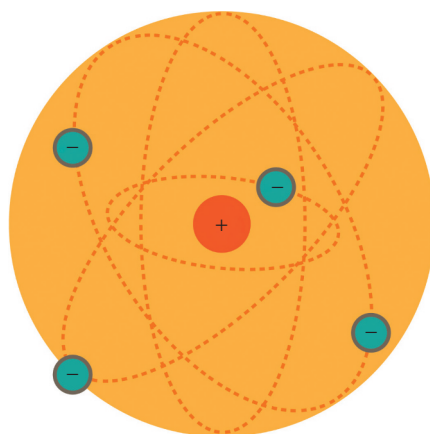


Figure N.60 Rutherford's atomic model of the nuclear atom, solid nucleus with no distinguishable constituents.

Nuclear binding energy

[atomic, nuclear] The nucleus contains approximately 99.975% of the total mass of an ATOM and hence the ENERGY requirements for dissociation are very high. The NUCLEAR BINDING ENERGY is the energy contained by holding the appropriate number of protons and neutrons together, and the energy released when a grouping of protons and neutrons is split off from the NUCLEUS. The total binding energy (BE) can be derived from the MASS ENERGY equivalence: $BE = \left[Zm_p + (A - Z)m_n - {}_Z m^A \right] c^2$, where Z is the number of protons (the atomic number) with m_p being the respective mass, A the atomic mass (with $A - Z$ the number of neutrons, with mass m_n), c the speed of light, and ${}_Z m^A$ the sum of the rest of the masses of the respective protons, neutrons, and remaining nucleus.

Nuclear bomb

[nuclear] An explosive device that releases nuclear ENERGY based on nuclear reactions of either fission or FUSION. The first fission bomb experimentally tested in 1945 (also referred to "ATOMIC BOMB") released approximately 20 kton (kilo-ton) of TNT (the explosive energy yield equivalent to the detonation of 20,000 ton {metric ton} of TNT); where 1 ton TNT = 4.184 GJ. The most popular isotopes used in the fission process are uranium-235 (enriched uranium) and plutonium-239. The first fusion bomb ignited in 1952, also referred to as "thermonuclear bomb" (the "hydrogen" bomb, which is actually a fission–fusion mechanism) released approximately 10 Mton TNT. The HYDROGEN BOMB uses uranium fission as the "detonator" for the hydrogen fusion process. The use of the description "atomic bomb" (A-BOMB) is a misnomer because the energy comes from the NUCLEUS. The FISSION process becomes self-sustaining when a critical mass of unstable medium is exceeded, slightly more than 10 kg of plutonium-239 surrounded by the U-238 ISOTOPE. The H-BOMB relies on the heat and pressure of fission initiated by the uranium explosion initiating the following process. Hydrogen-2, or {deuterium (${}^2\text{D}$)} fuses with hydrogen-3 {tritium (${}^3\text{T}$)} and

forms helium-4 (^4He) as well as one neutron (n) and energy ($E \approx 17.6 \text{ MeV} = 2.81983075 \times 10^{-12} \text{ J}$) that is converted in THERMAL EXPANSION and ELECTROMAGNETIC RADIATION: $^2\text{D} + ^3\text{T} \rightarrow ^4\text{He} + n + E$. Note that 1 kg of hydrogen contains 5.975×10^{26} atoms (see Figure N.61).

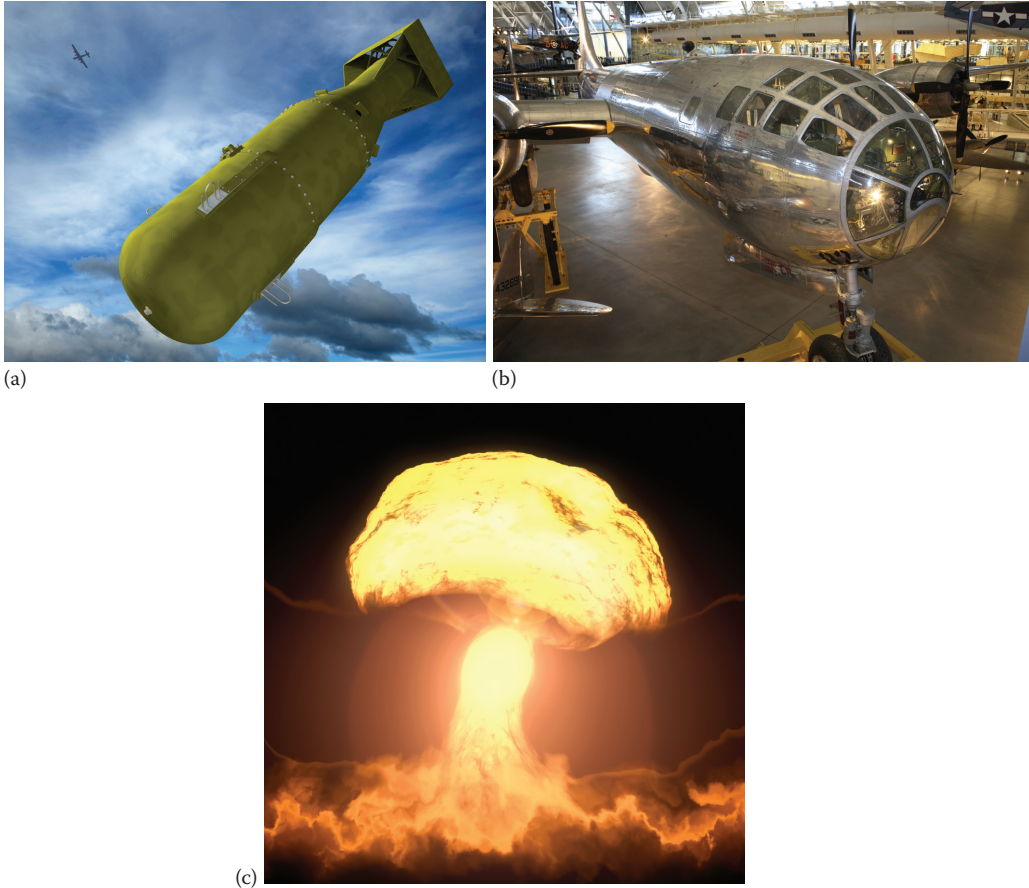


Figure N.61 Rendering of the (a) “Little Boy” atomic bomb targeted to be dropped on Hiroshima, Japan, on August 6, 1945 and (b) Boeing B-29 bomber: Enola Gay, used to deploy the “atom bomb” over Hiroshima, Japan as well as participated on the attack on Nagasaki, Japan, which resulted in the termination of the war offensive by Japan during the Second World War (1940–1945), (c) rendering of the pressure evolution, and condensation and debris “mushroom” cloud resulting from an above ground nuclear explosion.

Nuclear charge

[nuclear] Total charge resulting from the number of protons in the nucleus of an ATOM. The nuclear charge is indicated by the PROTON number Z (atomic number). This charge will affect the BINDING ENERGY of the electrons in their respective orbits. The charge configuration can be determined with the use of elastic electron SCATTERING cross sections and Bayesian probability distributions.

Nuclear coulomb barrier

[general] Because of the charge distribution of the NUCLEUS, an electric POTENTIAL BARRIER is created that can be accessed by TUNNELING or under FUSION the kinetic ENERGY of the incident PARTICLE needs to exceed the coulomb barrier. For fusion to overcome the electric repulsion, the fusing particle will need to get close enough to allow for the attractive nuclear strong force to be activated. The energy barrier is derived from the electrostatic potential energy: $U_{\text{Coulomb}} = (1/4\pi\epsilon_0)(q_1q_2/r) = (1/4\pi\epsilon_0)(Z_1Z_2e^2/r)$, where

ϵ_0 is the permittivity of free space, r is the separation between the two charges q_1 and q_2 , with the charge MAGNITUDE defined by the atomic number Z (also see QUANTUM TUNNELING).

Nuclear fission

[atomic, nuclear] Special type of nuclear transformation characterized by the splitting of a NUCLEUS into at least two other nuclei and the release of a relatively large amount of ENERGY. The most well-known FISSION process is that of uranium-235 (see FISSION) (see Figure N.62).

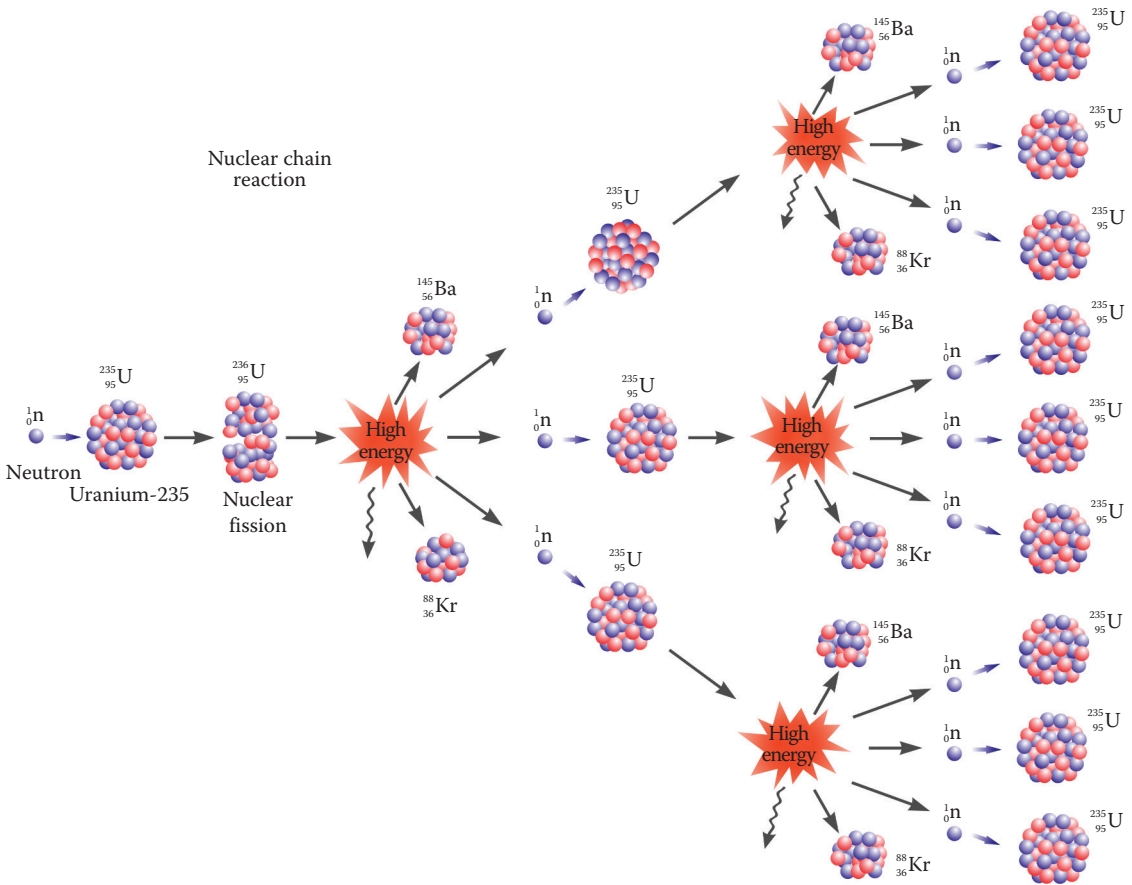


Figure N.62 Nuclear fission.

Nuclear force

[general] Nuclear forces can be distinguished as strong and weak nuclear forces, as part of the four principle force, including gravitational force and electromagnetic force. Weak nuclear force has a range of $10^{-17} \text{ m} = 10 \text{ am}$ (attometer) working between atomic constituents, quarks and leptons, and the strong force has a range of $10^{-15} \text{ m} = 1 \text{ fm}$ (femtometer), acting between subnuclear particles: quarks and gluons. Apart from the coulomb force acting between opposite and like charges, attractive and repulsive, respectively, the nucleon–nucleon force generally becomes negligible for a separation greater than $4 \times 10^{-15} \text{ m} = 4 \text{ fm}$ and is generally strong at smaller DISTANCE than 1 fm, stronger than the prevailing coulomb force:

$F_c = (1/4\pi\epsilon)(Z_1Z_2/r^2)$, where Z_i represents the respective charge on the two particles at distance r and $\epsilon = \epsilon_r\epsilon_0$; $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the DIELECTRIC permittivity, in VACUUM: “ ${}_0$,” and ϵ_r is the relative

permittivity. The large scale nucleon–nucleon attraction between the respective neutron–neutron, neutron–proton, or proton–proton configurations can be described in first order approximation by the SCHRÖDINGER EQUATION: $-(\hbar^2/M)\nabla^2\psi + V_{\text{elec}}\psi = i\hbar(\partial\psi/\partial t)$, where ψ is the two-nucleon WAVE FUNCTION, $\hbar = h/2\pi$, where $h = 6.63 \times 10^{-34}$ Js is Planck's constant, V_{elec} is the electrical potential of the BINDING ENERGY, $M = 939 \text{ MeV}/c^2$ is the NUCLEON mass (with a negligible difference between the PROTON and NEUTRON mass), ∇^2 is the Laplace operator representing the second order derivative in all dimensions, and t is the time. The potential V_{elec} is a function of the nucleon separation $\vec{r}$, the orientations of the spins of the two interacting nucleons $S^{(a)} = (1/2)\hbar$ and $S^{(b)} = (1/2)\hbar$, each with a SPIN component in the z -direction $S^{(i)} = \pm(1/2)\hbar$, yielding four possible spin configurations, each resulting in a 4×4 matrix for the potential and three matrix solutions for the three nucleon interaction combinations. In molecular PHYSICS, the interaction between two nucleons with the release of a PION (“ π ”) (i.e., π -meson), with mass m_π being represented by the potential equation: $V = \tau_a \cdot \tau_b g_\pi^2 (m_\pi/2M) \left[(1/3)(e^{-\mu_c r}/r)(\vec{\sigma}_a \cdot \vec{\sigma}_b) + ((1/3) + (1/\mu_c r) + (1/\mu_c^2 r^2))(e^{-\mu_c r}/r) S_{ab} \right]$, where $1/\mu_c = \hbar/m_\pi c = 1.4 \text{ fm}$ is the pion COMPTON WAVELENGTH, $\sqrt{g_\pi^2/\hbar c} \equiv$ is the pion-nucleon coupling constant, $\hbar = h/2\pi$, where $h = 6.6260 \times 10^{-16}$ Js is Planck's constant, $\vec{\sigma}_a$ and $\vec{\sigma}_b$ are the PAULI SPIN MATRICES for the respective nucleons a and b , τ_a and τ_b are the respective isospin matrix in 2×2 format for nucleon a and b , r is the nucleonic interspacing distance, c is the speed of light, g_π is the pion ENERGY, and $S_{ab} = 3(\vec{\sigma}_a \cdot \vec{r})(\vec{\sigma}_b \cdot \vec{r}) - (\vec{\sigma}_a \cdot \vec{\sigma}_b)$ is the TENSOR operator; the intrinsic spin can also be characterized as $S^{(a)} = \vec{\sigma}_a \hbar/2$.

Nuclear fusion

[atomic, nuclear, thermodynamics] The coalescing of two or more nuclei to form a new NUCLEUS with relative stability. The FUSION process requires penetrating the NUCLEAR COULOMB BARRIER, placing a high velocity constraint on the process, hence only operational under very high temperatures. The fusion process relies on QUANTUM TUNNELING, a process discovered in 1929 by German physicist Friedrich Hund (1896–1997). In the fusion process, some of the combined mass is converted into ENERGY, yielding a high energy EXOTHERMIC REACTION. The first successful attempt in nuclear fusion was made in 1932 by Australian physicist Mark Oliphant (1901–2000) with hydrogen isotopes. Substantial focused research was initiated in the early 1940s in the United States as part of the MANHATTAN PROJECT. Additional research in the development of THERMONUCLEAR FUSION for civil purposes was initiated in the early 1950s (see Figure N.63).

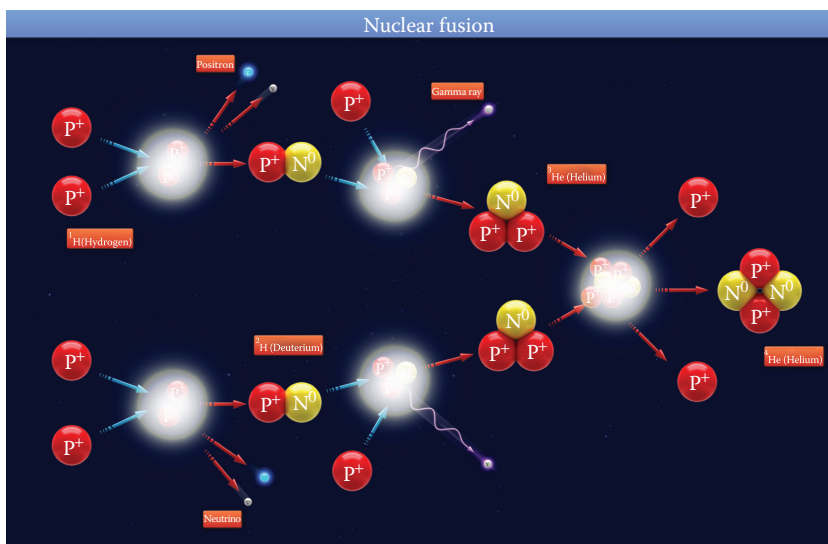


Figure N.63 Nuclear fusion.

Nuclear g-factor (g_n)

[atomic, energy, nuclear, optics] The spectral split under influence of the nuclear SPIN is determined by the influence of the nuclear spin and the interaction with the electron orbital MAGNETIC FIELD (see G-FACTOR, NUCLEAR. Also see ZEEMAN EFFECT and HYPERFINE STRUCTURE).

Nuclear magnetic moment

[atomic, nuclear] $\mu_{I_n} = g_n (m_e/M_n) (e/2mc) \vec{I}$, with g_n the nuclear g-factor, (m/M) the ratio of the electron mass (m_e) over the nuclear mass (M_n) and $\vec{I}$ the nuclear SPIN.

Nuclear magnetic resonance (NMR)

[general] See MAGNETIC RESONANT IMAGING (MRI).

Nuclear magneton (nm)

[atomic, nuclear] The MAGNETIC MOMENT (MM) associated with the intrinsic spin of nuclear particles is expressed in unit nuclear magneton: $nm = (e\hbar/2m_p) = 5.0505 \times 10^{-27} \text{ Jm}^2/\text{Wb}$; for a PROTON, this is $MM_{\text{proton}} = 2.79275 \text{ nm}$, and for the NEUTRON, $MM_{\text{neutron}} = -1.9135 \text{ nm}$.

Nuclear medicine

[atomic, biomedical, computational, general, imaging, solid-state] Therapeutic applications that use radioactive isotopes to create selective modifications to the biological DNA or cause CELL death as well as rely on the selective incorporation of radioactive isotopes in a metabolic event to be used for imaging purposes. In imaging, the use of iodine ISOTOPE is one of the mechanisms that allow for monitoring the ACTIVITY of the thyroid by means of a gamma CAMERA. Another application in positron emission TOMOGRAPHY imaging is the use of fludeoxyglucose isotope (active component: positron emitting fluorine-18), known as “fluorodeoxyglucose” as a RADIOPHARMACEUTICAL used as a GLUCOSE replacement for metabolic imaging. Cancer treatment uses radiopharmaceuticals that are designed to go directly to the organ considered for treatment, for example rhodium (^{105}Rh) and rhenium-188, mostly used as beta emitters to inflict CELL death. In therapeutic applications, the success will hinge on the target to nontarget differentiation of uptake of the peptide or other molecular structure (see Figure N.64).

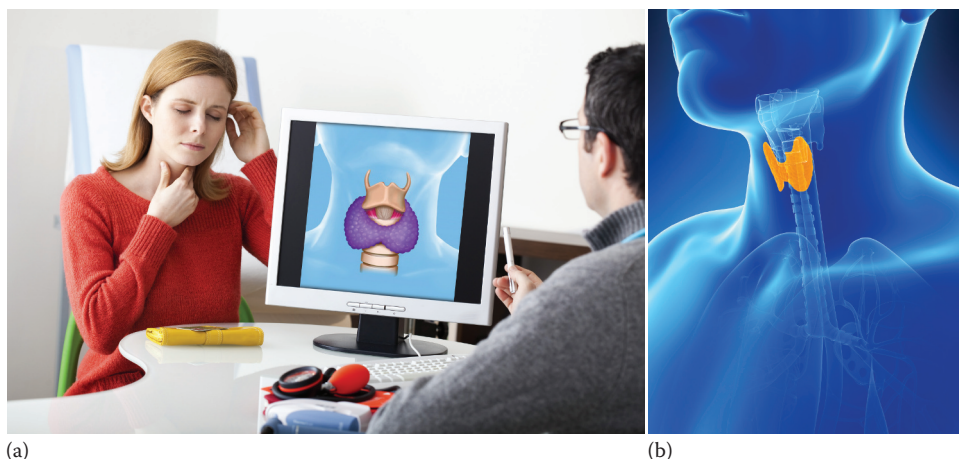


Figure N.64 (a) Illustration of the thyroid gland and (b) the treatment of thyroid cancer is one application of nuclear medicine.

Nuclear microscope

[general, nuclear] Force probe microscopy on ATOM scale (*also see* ATOMIC FORCE MICROSCOPE).

Nuclear models

[nuclear] Various models are available to describe the nuclear structure, based on energetic configuration or resulting from historical observations. Some of the models available are collective model, compound NUCLEUS model, direct reaction model, LIQUID-DROP MODEL, Rutherford model, and Bohr SHELL MODEL.

Nuclear reactor

[atomic, nuclear] Power-generating mechanism based on NUCLEAR FISSION or FUSION, creating steam to drive turbines that generate ELECTRICITY for general consumption. The general construction of a nuclear reactor has RODS of various composition suspended in a LIQUID. The fuel rods form the principle nuclear reaction, such as uranium-235 in a FISSION reactor; balanced by control rods that can partially capture the emissions driving the nuclear reaction, hence controlling the rate of the reaction, as well as the liquid itself which is known as the MODERATOR and often consists of "HEAVY WATER," a mixture of bound oxygen molecules tied to deuterium or tritium, replacing the standard hydrogen in water. The bath is surrounded by a concrete shield for absorption of stray emissions. In the nuclear conversion process the base for the fuel is obtained from various locations, each with specific grade of purity and contamination. The mined components will require processing, that is, enrichment, before it can be used in a nuclear reactor. An additional step in the preparations before use in the power station is the fabrication of the fuel rods from the enriched uranium, for instance. The steam GENERATOR is separated from the reactor vessel to avoid contamination, and relies on a heat exchanger to transfer the heat from the REACTOR to the steam generator. The steam is maintained in a closed circuit at pressures on the order of 0.5 mPa or greater. The steam is lead through the TURBINE from where it is cooled by a CONDENSER that vents to the outside by means of the cooling towers. A different type of nuclear reactor is the breeder reactor, which produces fuel for fission in parallel with generating power, producing plutonium-239 from uranium-238. Spent fuel will remain radioactive for several hundred years, up to in excess of a thousand years (depending on the accepted cut-off emission threshold), and requires an elaborate system of waste-management. Because of the high ENERGY radiation produced during the DECAY mechanism, nuclear power plants have a high risk associated with their operation. The first fission reactor was made operational in 1951 near Arco, Idaho. Several accidents with nuclear reactors have resulted in

long-term damage to the area in which the reactor was placed, for instance, Three-mile Island in Dauphin County, Pennsylvania (1979); Chernobyl in the former USSR, now Russia (1986), and the Fukushima Daiichi plant in Okuma and Futaba, Japan (2011). Additional accidents have involved the unplanned release of radioactive steam into the ATMOSPHERE and RADIATION leaks through cracks in the shielding concrete WALL of the reactor. An example of a natural FUSION REACTOR is the Sun, additional artificial fusion nuclear power plants have been created based on the tokamak principle. The first tokamak base fusion reactor was build and operated in Novosibirsk in 1968 (see [Figure N.65](#)).

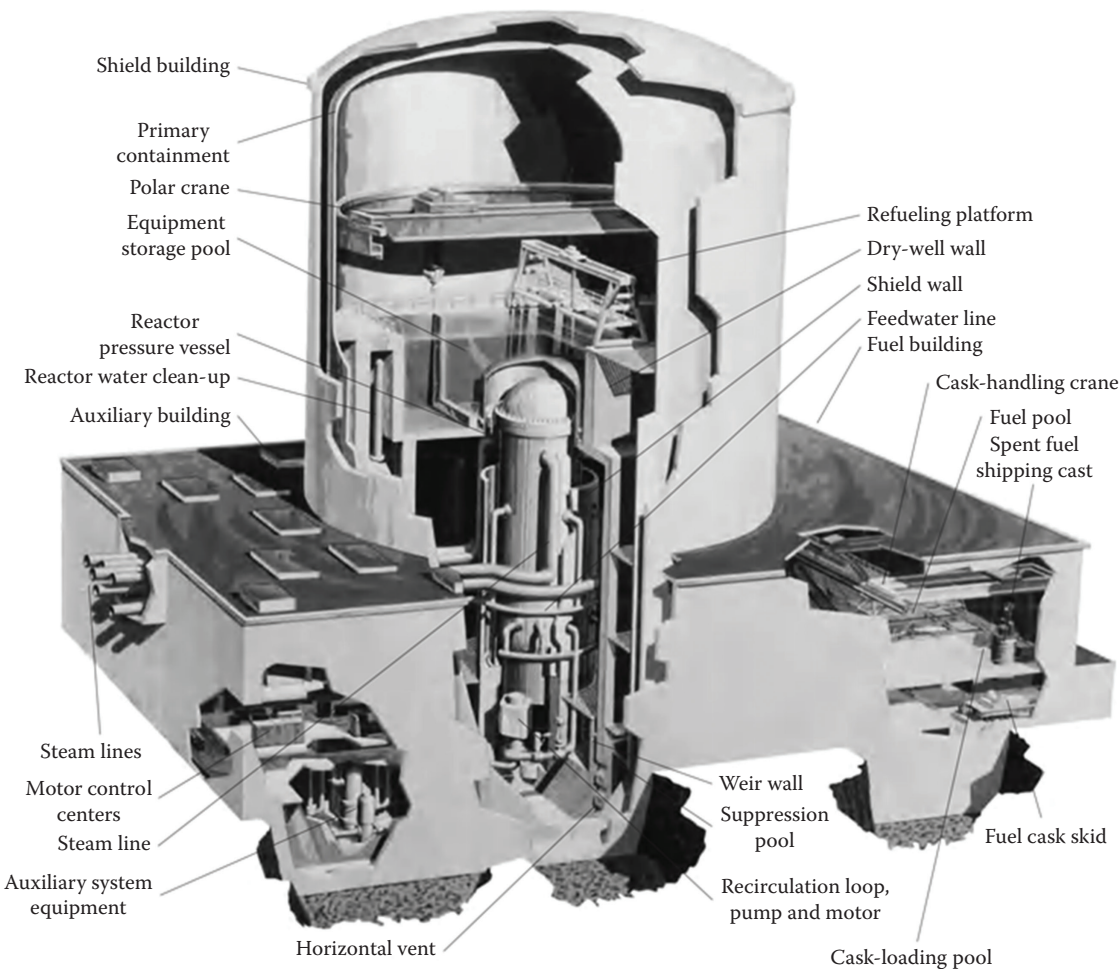


Figure N.65 Nuclear power plant reactor design. (Courtesy of General Electric Corporation [GE], Fairfield, CT.)

Nucleation

[fluid dynamics, general, mechanics] Process of BUBBLE formation, followed by collapse (CAVITATION). Formation of temporary voids in a LIQUID resulting from thermal agitation (i.e., boiling or PLASMA formation [the latter in the case of both solid and liquid media]), growing from MICROSCOPIC to MACROSCOPIC proportions (*see* CAVITATION) (*see* Figure N.66).

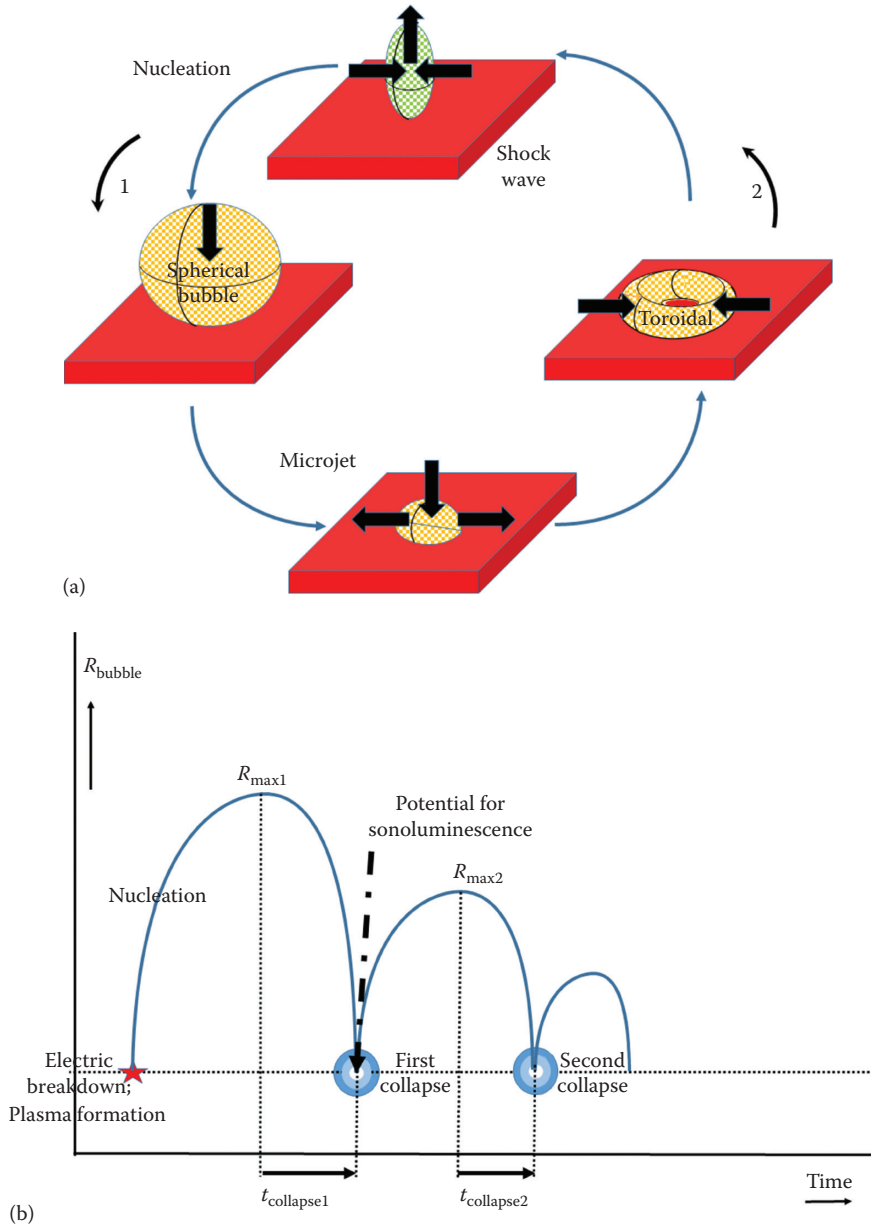


Figure N.66 (a) Progress of bubble formation and (b) nucleation.

Nucleon

[nuclear] The common name for the constituent parts of the NUCLEUS. At present applied to protons and neutrons, but will include any other PARTICLE that is found to exist in the nucleus (see Figure N.67).

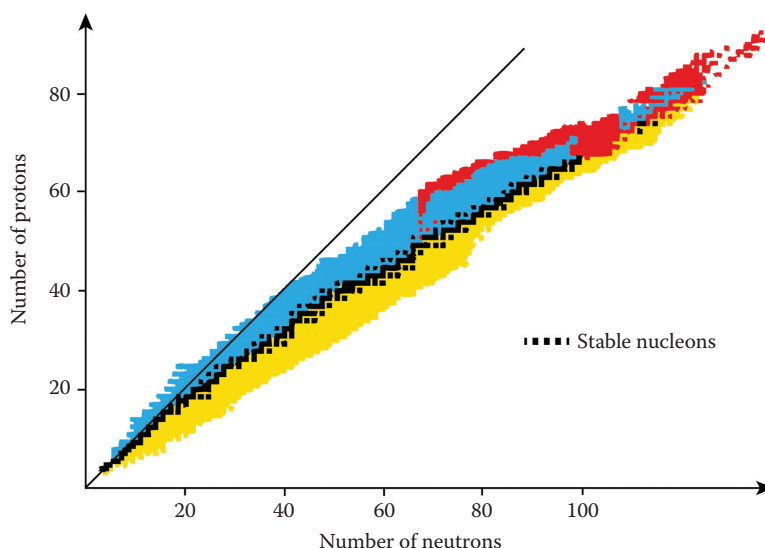


Figure N.67 Chart of nuclides. Nucleon pattern, proton versus neutron assembly.

Nucleon configuration

[atomic, nuclear] The NUCLEUS consists of protons identified by the atomic number Z and neutrons indicated in quantity by N . The following configurations for the nuclear make-up can be recognized: even proton-even neutron (even-even), odd proton-odd neutron (odd-odd), odd proton-even neutron (odd-even), even proton-odd neutron (even-odd). The even-even configuration has an even mass number ($Z + N = A$); note that the electron mass ($m_e = 0.0005446623 \text{ amu} = 9.10938188 \times 10^{-31} \text{ kg}$) is negligible compared to the NEUTRON mass $m_n = 1.0086649156 \text{ amu} = 1.6749 \times 10^{-27} \text{ kg}$ and proton mass $m_p = 1.00727638 \text{ amu} = 1.6726 \times 10^{-27} \text{ kg}$. The even-even configuration is the largest population of ELEMENTS with 148 stable nuclides with an additional 21 long-lived radio-active nuclides, the odd-odd group contributed only 5 stable atomic structures and 4 long-lived primordial nuclear ISOMERS, the odd-even configuration has 48 stable nucleons with an additional 5 long-lived nuclides, and the even-odd nuclei total 53 stable and 3 long-lived isotopes. All even-even nuclei have a base total nuclear SPIN of $s = 0$ in GROUND STATE, the odd-odd nuclides have integer spin; however, none has spin zero. All remaining nuclides with odd mass-number are classified as fermions, meaning that the total spin is half-integer, and have an array of spin number orientations.

Nucleus

[nuclear] The heavy central part of an ATOM in which most of the mass and the total positive ELECTRIC CHARGE are concentrated, greater than 99.975%. The charge of the NUCLEUS, an integral multiple Z of the charge of the PROTON, is the essential factor that distinguishes one ELEMENT from another. Z is the atomic number. The net POSITIVE CHARGE of the nucleus forms the attractive mechanism for orbiting electrons defined by the coulomb force.

Nuclide

[nuclear] General term referring to all nuclear species and isotopes, both stable (known so far 275) and unstable (approximately 500), of the chemical ELEMENTS known and listed in the PERIODIC TABLE OF ELEMENTS (see NUCLEON).

Numeric evaluation

[acoustics, computational, general, optics] Mathematical analysis based on function association, tying parameters together. When the mathematical correlation becomes too complex, the function may be solved numerically by insertion of incremental steps. One specific example of a NUMERICAL analysis is in the propagation of ELECTROMAGNETIC RADIATION through SCATTERING media, as applied to galactic dust and in biomedical applications for the EQUATION OF RADIATIVE TRANSFER. Additional numerical analyses are common in FLUID DYNAMICS due to the complex boundary conditions of a system of interest, providing a three-dimensional result that is location specific and varies with time.

Numerical

[computational, fluid dynamics, general, optics] The mathematical approach for solving equations by means of taking numerical incremental steps and solving step-wise with numerical data point solutions that are logged and graphically represented. An analytical solution stands in contrast to a numerical approach, both providing an equation all the same.

Numerical aperture

[general, optics] (NA) introduced by ERNST ABBE (1840–1905) as $NA = n \sin \theta$, with θ is the maximum half—solid-angle of the “hypothetical” cone defined at the surface of an optical device (e.g., LENS, fiber-optic face) within which light can exit or enter the optical device and n is the INDEX OF REFRACTION of the medium in which the lens is placed. Parameter for optical devices that describes the relationship between the maximum APERTURE to the focal length of, for instance, a compound lens system. The numerical aperture is defined by half the acceptance ANGLE (θ) of the device and the index of refraction of the medium (n) through which the ELECTROMAGNETIC RADIATION travels as $NA = n \sin \theta$. Hence, the numerical aperture can be increased by placing a drop of OIL between the specimen on a MICROSCOPE slide and the objective of the microscope. The numerical aperture is an indication of the light gathering capability of an optical system, the larger the better (see Figure N.68).

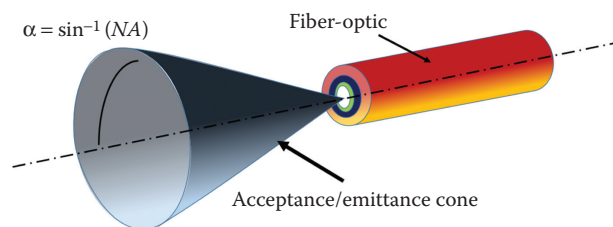


Figure N.68 Numerical aperture.

Numerical fluid mechanics

[computational, fluid dynamics] Computational techniques for solving Navier–Stokes equations as well as finite ELEMENT techniques for three-dimensional solutions. The finite element methods will generate a grid pattern that has variable RESOLUTION depending on the geometric and anticipated FLUID DYNAMICS complexity within a certain volume. The computational aspects are geared to finite differences approximations for elliptic, parabolic, and hyperbolic equations. Often, the NUMERICAL approach uses Fourier decomposition and requires error analysis to establish the validity of the SOLUTION and within what domain. In particular, the use of numerical analysis applies to turbulent flow characteristics and boundary conditions. The time-resolved assessment is also very useful for flow development and time perturbation analysis (*also see COMPUTATIONAL FLUID DYNAMICS*).

Nusselt (Nußelt), Ernst Kraft Wilhelm (1882–1957)

[biomedical, fluid dynamics, thermodynamics] An engineer and scientist from Germany. Nusselt developed the dimensional HEAT TRANSFER analysis (see Figure N.69).

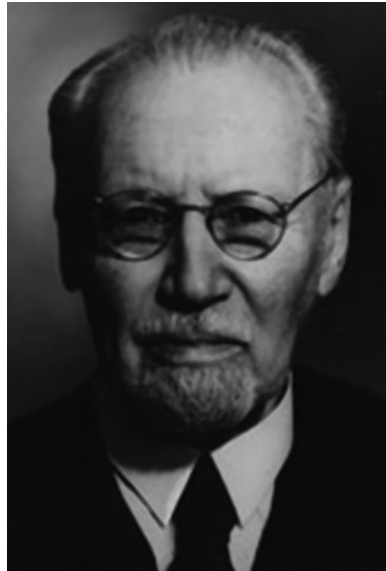


Figure N.69 Ernst Kraft Wilhelm Nusselt (Nußelt) (1882–1957). (Courtesy of Technische Universität (TU) Dresden, Dresden, Germany.)

N

Nusselt number ($Nu = h_i L / \kappa$)

[fluid dynamics, thermodynamics] Dimensionless number identifying the temperature gradient at a surface, for instance, under FLOW or condensation; it was introduced by ERNST KRAFT WILHELM NUSSALT (Nußelt) (1882–1957); this surface phenomenon relates to BOUNDARY LAYER or condensate film respectively. (Note that for condensate film, $Nu = \bar{h}_i L / \kappa = c \left[(\rho_\ell g (\rho_\ell - \rho_v) h_{fg} L^3) / (\eta_{\text{molec}} \kappa_l (T_{\text{sat}} - T_w)) \right]$, where L is the characteristic dimension of the phenomenon, κ is the THERMAL CONDUCTIVITY, and $\bar{h}_i$ is the HEAT TRANSFER coefficient, $\bar{h}_i$ is the average heat transfer coefficient for condensation of a film respectively, ρ_ℓ is the density of the VAPOR, ρ_v is the density of the vapor, g is the GRAVITATIONAL ACCELERATION, h_{fg} is the LATENT HEAT of vaporization, η_{molec} is the molecular viscosity, κ_l is the thermal conductivity of the LIQUID, T_{sat} is the SATURATION temperature of the vapor, T_{sat} is the surface temperature, and constant c is dimensionless and accounts for size and shape. From this, it becomes evident that for smaller bodies, (characteristic dimension small) the heat transfer coefficient is larger than for large bodies. The definition of the Nusselt number is the transport of THERMAL ENERGY ratio between that under forced convection to that of conduction. As with any dimensionless number, the role is to reduce the quantity of independent variables.

Nutation

[astrophysics/astronomy, biomedical, mechanics] Rocking, oscillating, swaying, or bobbing MOTION of the axis of rotation of a predominantly axially symmetric object. This MOTION may pertain to the earth's rotation, a GYROSCOPE. Additionally, certain plants have slow or fast nutation resulting from unequal rate of growth at respective different sides (sunflowers orient themselves toward the Sun as the day passes). Other examples are the sensitivity of certain plants to temperature, such as the tulip and the crocus. The crocus can distinguish a temperature change of 0.5°C and will change its orientation/inclination in response to a

temperature change of 20°C within 2 min. In biology, there is the pivotal motion of the sacrum (gyration, in reference to the dance moves by Elvis Presley [1935–1977]), which is a large, triangular bone at the base where the spine meets the pelvic bone (*also see* PRECESSION) (see Figure N.70).



Figure N.70 Nutation spinning top stays erect, but “wobbles” about the equilibrium.

Nuttall, John Mitchell (1890–1958)

[atomic, nuclear] A physicist from Great Britain. John Nuttall discovered the regularities of DECAY rates for even-even nuclei (even number of protons [Z]; even number of neutrons [N]) and introduced the decay constant. He has been a collaborator with Hans Geiger on the detection of RADIATION. The collaborative efforts resulted in the GEIGER–NUTTALL LAW of RADIOACTIVE DECAY: $\log \lambda = a + b \log r_{\text{range}}$, where λ is the decay rate, r_{range} is the range of radiation in AIR, a is a material parameter, and b is a constant.

Nylon

[biomedical, chemistry] It is a synthetic POLYMER. Nylon is a versatile material used in many consumer and industrial applications as well as in biomedical use for prosthetic construction and reinforcement, also used as suture material and sewing wire. Nylon is a diverse family of products that were initiated at DuPont in 1935 by Wallace Carothers (1896–1937). Nylon as a generic definition is a polyamide of repeating chemical units that are linked by amide bonds. Nylon is a copolymer formed through condensation of diamine and a dicarboxylic ACID, in equal parts, forming the amide chains. Nylon was used initially in broom brushes and shortly thereafter in lady’s stockings (“nylons,” introduced in the 1940s). Nylon can withstand high temperatures and as a solid sheet can be press-molded into most any shape and has a MELTING POINT of

256°C. Nylon has a high tensile strength and is used as rope for a broad range of applications, including hoisting heavy equipment (see [Figure N.71](#)).



Figure N.71 (a–f) Illustrations of the use of Nylon.

Nyquist, Harry Theodor ("Nyqvist") (1889–1976)

[computational, thermodynamics] A Swedish electrical engineer and physicist. Nyqvist worked for AT&T and Bell laboratories. In 1960, Nyquist received the IRE Medal of Honor from the Institute of Radio Engineers, for his involvement in the description of "fundamental contributions to a quantitative

understanding of thermal NOISE, data transmission and negative feedback.” His collaborative work with CLAUDE ELWOOD SHANNON (1916–2001) led the foundations for information theory and SIGNAL sampling principles, additionally his work with Herbert Eugene Ives (1882–1953) formed the roots for feedback control theory (see [Figure N.72](#)).



Figure N.72 Harry Theodor Nyquist (“Nyqvist”) (1889–1976). (Courtesy of IEEE.)

Nyquist frequency

[computational] The highest frequency component that can be distinguished at half the frequency at which data acquisition is performed. The Nyquist frequency provides a discrete data array as a function of time. This concept was proposed by HARRY THEODOR NYQUIST (1889–1976).

Nyquist rate

[computational] The minimum sampling frequency that needs to be applied to obtain the frequency resolution of the highest rate of change in an observed phenomenon, obtained at a RESOLUTION that is half the Nyquist rate sampling frequency, as a continuous-time signal. Introduced by HARRY THEODOR NYQUIST (1889–1976). Sampling at lower rates (i.e., undersampling) may result in ALIASING, where DRIFT between separate signals is not captured as individual data streams; this may be linked to two separate signal functions (separate sources) that produce similar data streams, which can be out of PHASE. Oversampling will cost in processing time and can result in missed data points or introduce NOISE.

Nyquist–Shannon sampling theory

[computational] The SAMPLING rate for data acquisition for an observation will need to be at least twice the frequency of the phenomenon under observation in order to retrieve all frequency information imbedded in the events, and subsequently separate out individual events and factors driving the manifestation of physical parameters. This principle was introduced by HARRY THEODOR NYQUIST (1889–1976) and CLAUDE ELWOOD SHANNON (1916–2001). If an observation in time $f(t)$ is confined to a maximum

frequency of $v^* H_z$, the phenomenon is fully determined by a data array with time spacing of samples information at $(1/v^*)s$ intervals (*also see* **NYQUIST FREQUENCY**) (see [Figure N.73](#)).

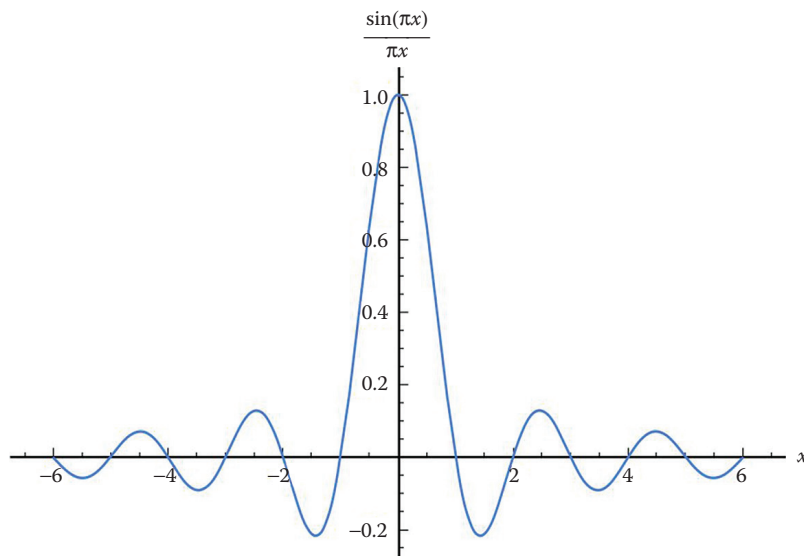


Figure N.73 Mathematical mechanism of action used to interpolate the numeric sequence during signal sampling can be described by sinc functions.

Nystagmus

[biomedical, mechanics] The locking **MOTION** of the eyes on a target point during rotation of the body followed by a slow tracking when the observational limit is reached. The quick reflect of the **EYE** followed by slow deviation tracking is nystagmus. Nystagmus can consist of rotational, horizontal, or vertical motion. In humans, the irritation of the labyrinth of the **EAR** used for equilibrium can cause random eye motions; one aspect is the irrigation of the ear by cold water resulting in involuntary nystagmus. Nystagmus also provides a tool for the analysis of certain brain disorders. Additionally, nystagmus can be used to describe the uncontrollable motion of the eye as a clinical condition (“dancing eye,” affecting one in several thousand people) (see [Figure N.74](#)).

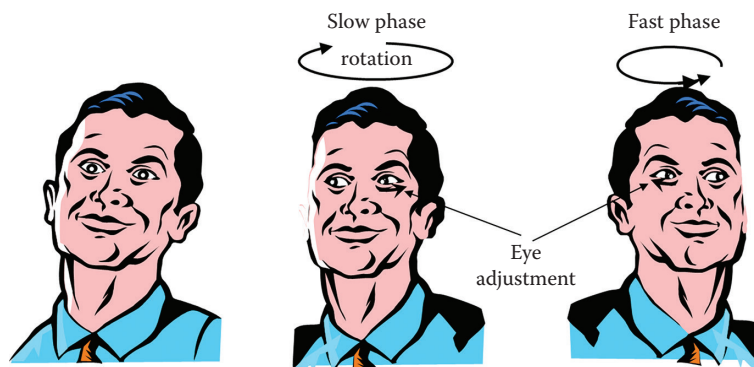


Figure N.74 Nystagmus.



Oak Ridge National Laboratory

[atomic, nuclear] Oak Ridge, Tennessee, was established in 1942 as a uranium enrichment production site for the MANHATTAN PROJECT. The city still hosts a major concentration of basic and applied research. The Oak Ridge National Laboratory and the University of Tennessee are combining their effort, supported by federal and state funding and a public research. The Oak Ridge National Laboratory is the largest US Department of Energy research facility, focusing on multifaceted and multidisciplinary science and technology research, managed by UT-Battelle, LLC (see [Figure O.1](#)).



Figure O.1 Oak Ridge National Laboratory. (Courtesy of the United States Department of Energy, Washington, DC.)

Obert, Edward F. (1910–1993)

[thermodynamics] A scientist and engineer from the United States. The work of Obert includes the published charts illustrating the “PRINCIPLE OF CORRESPONDING STATES” with L.C. Nelson in

1954, referring to the work of JOHANNES DIDERIK VAN DER WAALS (1837–1923), published in 1880 (see [Figure O.2](#)).



Figure O.2 Edward F. Obert (1910–1993) on right during the award of the Benjamin Smith Reynolds Award for outstanding contributions to the teaching of engineering students, May 4, 1973. (Courtesy of the University of Wisconsin-Madison College of Engineering, Madison, WI.)

Object wave

[general] Light incident on an object is diffracted, forming a collective WAVE front of scattered light that is subject to superposition generating a collective WAVEFRONT referred to as the “object wave” (see [Figure O.3](#)).

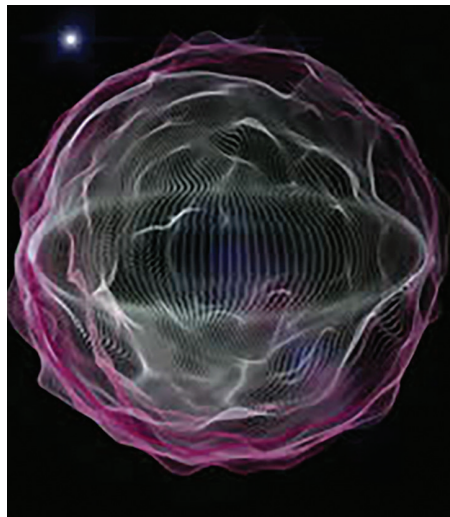


Figure O.3 Representation of the appearance of an object wave pattern.

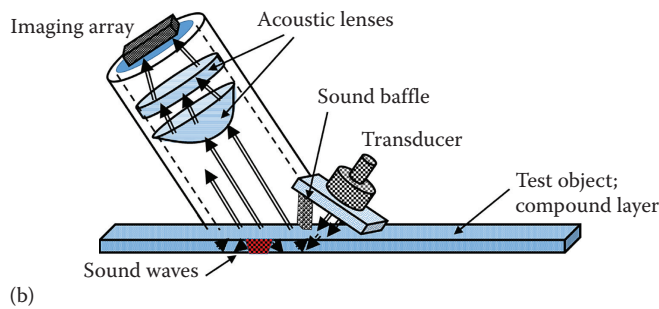
Oblique angle scanning

[acoustics] Scanning of multilayered targets with ULTRASOUND, specifically using pulse-echo detection, yields reverberations that complicate the direct characterization of the composition of the medium. Under oblique ANGLE detection, the first order reverberant echoes are rejected, hence providing a more clearly

defined ultrasound SIGNAL with greater detail. Similar principles also apply in positron emission TOMOGRAPHY imaging. The oblique angle SCATTERING brings about considerable artifacts that interfere with proper IMAGE formation (see Figure O.4).



(a)



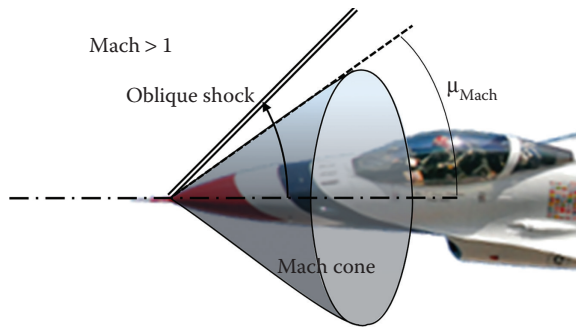
(b)

Figure O.4 (a) Oblique angle deflection providing characteristics about the structure and composition of a medium and objects within a medium. For instance, the mere visual recognition of the material (metal, plastic, ivory, or wood) in this optical scatter image of chess pieces as well as the identification of the isolated pawn. (b) Oblique detection angle for ultrasound imaging.

Oblique shock wave

[fluid dynamics] A SHOCK WAVE propagation traveling with inclination with respect to the incident upstream FLOW direction, unlike a normal shock. An oblique shock wave is generally formed at the tip (wedge) of an object in supersonic, compressible, flow. An example is the thermodynamic discontinuity at the nose of a plane approaching, and subsequently exceeding Mach velocity. The WAVE is at this point deflected at an corner angle (θ), diverting with respect to the streamlines: α , the oblique shock angle, conforming to: $\tan \theta = 2 \cot \alpha [(M_1^2 \sin^2 \alpha - 1) / M_1^2 (\gamma_{hc} + \cos 2\alpha + 2)]$, where M_1 represents the MACH NUMBER, and γ_{hc} the heat capacity ratio. The MACH WAVE itself is only an infinitesimally weak shock wave. The coalescing of a

multitude of Mach waves originates an actual oblique shock wave, similar to the normal shock wave. The flow direction of the oblique shock wave is tangential to the surface of the disturbance. Similar principles also apply to NOZZLE flow (see [Figure O.5](#)).



(a)



(b)

Figure O.5 (a) Principle of oblique shock wave and (b) low frequency shockwaves for joint therapy.

Occhialini, Giuseppe ("Beppo") Paolo Stanislao (1907–1993)

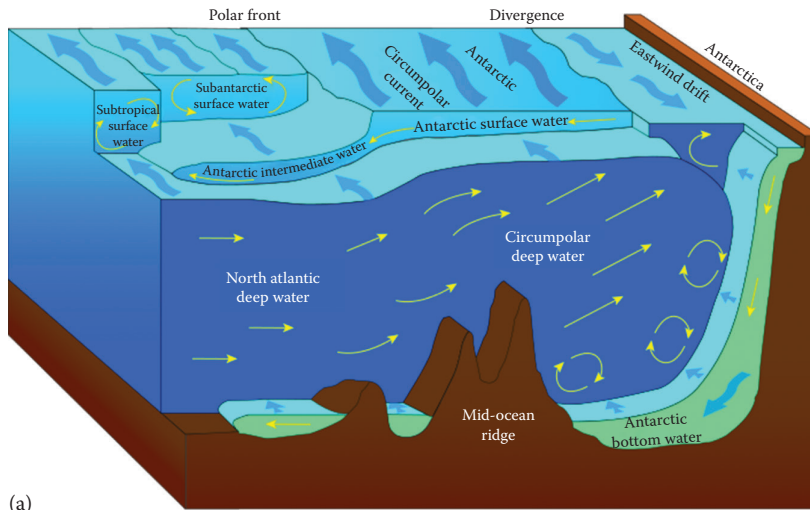
[astrophysics/astronomy, nuclear, thermodynamics] A geophysicist from Italy involved in the identification of COSMIC RAYS, concerning charge and ENERGY. He is a close collaborator with PATRICK BLACKETT (1897–1974). Giuseppe Occhialini also contributed to the discovery of the pi-meson (PION) in 1947, while the other associates of the research team that all received the Nobel Prize in Physics are César (Cesare) MANSUETO GIULIO LATTES (1924–2005) and CECIL FRANK POWELL (1903–1969) (see [Figure O.6](#)).



Figure O.6 Giuseppe ("Beppo") Paolo Stanislao Occhialini (1907–1993) in 1925. (Courtesy of the Università degli Studi di Milano-Bicocca, Milan, Italy.)

Oceanography

[energy, fluid dynamics, general, geophysics] A field of PHYSICS dealing with physical phenomena in the LIQUID part of EARTH'S ATMOSPHERE directly related to the FLOW and PHASE transitions of the oceans and large and small bodies of water, also referred to as "MARINE GEOPHYSICS" (*see* HYDROLOGY) (*see* Figure O.7).



(a)



(b)

Figure O.7 (a) Geographic description of the Antarctic Ocean water composition and (b) 1872 hypothetical description of a cross section of the Atlantic Ocean, limited due to incomplete information as a result of unavailability of instrumentation.

Octane number

[chemical, mechanics] A fossil fuel standard that represents the reciprocal of the PROBABILITY that an ENGINE will have incomplete combustion as a result of spark ignition in a four-stroke engine. An octane number of 100 represents perfect combustion and is rated based on isooctane (2,2,4-trimethylpentane,

C_8H_{18}). The number will depend on the compression ratio of the piston/cylinder configuration. The octane number of a fuel is determined in the “cooperative fuel research knock-test engine,” which has a variable compression ratio (see [Figure O.8](#)).



Figure O.8 Gasoline pump with octane numbers for the different grades of fuel.

Octave

[acoustics] Particular to music, the interval between one PITCH and another with double or half the respective frequency. The concept dates as far back as PYTHAGORAS (c. 570–490 BC). Musical notes that are one or several octaves apart are represented by the same letter symbol (C, D, E, etc.). In ELECTROMAGNETIC THEORY, the same applies; the best example is the visual response of the HUMAN EYE is approximately one octave: 325–650 nm, within certain luminescent boundaries. Octave equivalence denotes the fact that certain resonant frequencies share many of the same overtones. Octave equivalence refers to the format of the affinity of tones, synonymous to similarity. A concept referred to as “octave equivalence” has been observed in human infants and rats. This refers to the sensory octave affinity, which is based on commonality of multiple pitches in harmonic complex tones (see [Figure O.9](#)).

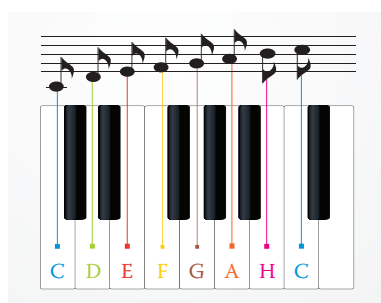


Figure O.9 Outline of piano keys over the spectral band of an octave.

Octave stretching

[acoustics, computational] The fact that octaves derived historically are not perfect 2:1 ratios. Octave stretch of tones of musical instruments was described by John F. Corso (1920–2013) in 1954.

Ohm, Georg Simon (1789–1854)

[biomedical, electronics, general, thermodynamics] A physicist and scientist from the Holy Roman Empire or Prussia, Germany. The scientific deductions of Georg Ohm while performing experimental observations with the electrochemical cell, GALVANOMETER from ALESSANDRO VOLTA (1745–1827), made him derive the relationship between current and applied electrical potential (voltage) and the associated electrical RESISTANCE known as “OHM’S LAW” (see [Figure O.10](#)).



Figure O.10 Georg Simon Ohm (1789–1854).

Ohm meters

[general] A portable instrument for measuring a broad range of values for electrical resistance pertaining to CONDUCTOR, SEMICONDUCTORS, and insulating devices. The ohmmeter is an active device, working based on an applied constant current, the RESISTANCE between two points can be derived using OHM’S LAW. Care needs to be taken that the contact resistance is negligible, between the measuring probe and the device (see [Figure O.11](#)).



Figure O.11 Ohm meter, part of a multi-meter.

Ohm's law

[biomedical, electronics] A relationship derived by GEORG SIMON OHM (1789–1854) describing the current through a RESISTOR (R) resulting from an applied electrical potential across the resistor of V is defined by $I = V/R$ (see Figure O.13).

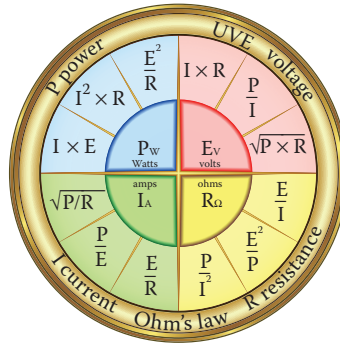


Figure O.13 Ohm's law and associated definitions.

Ohmic circuit element

[general] Electronic device that maintains a linear relationship between the applied potential and the current FLOW (see Figure O.12).

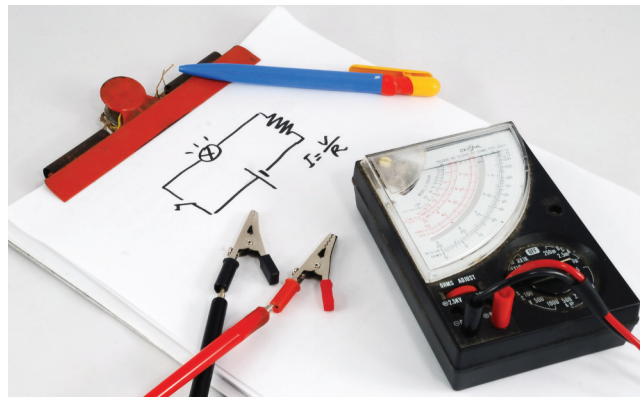


Figure O.12 Drawing of ohmic circuit diagram.

Ohnesorge number ($Z = \eta / (c_z \sqrt{\rho L \sigma})$)

[fluid dynamics, mechanics] A dimensionless number indicating the ratio of the net viscous force to the equalized inertial and surface forces (e.g., SURFACE TENSION OR FRICTION), which is expressed as the square root of the product of the latter two forces, with η the VISCOSITY, c_z dimensionless constant, ρ the density of the LIQUID, L the characteristic dimension of the phenomenon, and σ the surface tension. The Ohnesorge number is primarily used in the classification of momentum transfer, for instance, in ATOMIZATION.

Oil

[chemical, fluid dynamics, mechanics] Fossil residue that has many chemical applications, ranging from combustible fuel to lubricants and the production of PLASTICS. Oil is neutral in charge and nonpolar. The substance is a viscous LIQUID that is hydrophobic as well as lipophilic, OIL will float on water and mix with fatty substances. Crude oil or petroleum is the most recognized base material; however, plant and seed extracts are also referred to as “oils.” Next to petrochemical crude oil, we know mineral oil and sunflower oil as well as other plant products and animal oils. Chemically, oils are liquids with a high carbon and hydrogen content. Oils have applications in painting, cooking, cosmetics, LUBRICATION, base ELEMENTS for generation of chemical components, and fuels, and have attributes that make them effective HEAT TRANSFER media (e.g., high thermal conductivity, high flash point, and high vapor point). When a thin layer of oil covers a large surface of water, the mechanical properties of the water are directly affected as expressed by the modifications to the WAVE phenomena. The oil film results in a reduction of the AMPLITUDE of the water waves and also affects the Fourier spectrum of the wave phenomena, eliminating higher order frequencies (see [Figure O.14](#)).



(a)



(b)

Figure O.14 (a) Oil rig (oil platform) used for drilling for oil and (b) olive oil.

Oil-drop experiment

[atomic, nuclear] An experiment devised by ROBERT ANDREWS MILLIKAN (1868–1953) to determine the elementary ELECTRIC CHARGE (see **MILLIKAN OIL-DROP EXPERIMENT**).

Oil-film method

[fluid dynamics] Mechanism to provide a fast and simple approach to help validate computational FLUID DYNAMICS numerical simulations of fluid flow. Colored OIL injected in or floating on top of a fluid-dynamics process will provide a visual display of the FLOW processes, and boundary phenomena.

Old quantum theory

[general, quantum] Early theoretical results in QUANTUM MECHANICS from 1900 to 1925, based on Bohr–Sommerfeld quantization, which predate modern quantum mechanics. The original principles of QUANTUM THEORY were introduced in 1905 by ALBERT EINSTEIN (1879–1955), describing the quantum theory of light. The principles of the old quantum theory rely on the fact that MOTION in an atomic system is discrete and can be quantized. Such as system generally obeys classical mechanics with the exception that not every motion is allowed; only the motions that obey the old quantum condition are allowed: $\oint_{H(p,q)=E} p_i dq_i = n_i h$, where $H(p, q) = E$ is the Hamiltonian of the motion, p_i denotes the momentum values of the system and the q_i denotes the corresponding coordinates, n_i is the respective quantum numbers and $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is PLANCK'S CONSTANT. The integral is taken over one period of motion, taken at constant ENERGY, which is defined by the Hamiltonian.

Oncotic pressure

[biomedical] A specific form of OSMOTIC PRESSURE under the Starling principle: COLLOID OSMOTIC PRESSURE, partial pressure (Π) resulting from the large protein molecular solution in BLOOD or biological PLASMA (note that the protein cannot transport through the MEMBRANE of the vessel wall): $\Pi = -(RT/V) \ln(x_{\text{sol}}) \Rightarrow iMRT$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the GAS constant, T is the TEMPERATURE, V is the VOLUME, $x_{\text{sol}}^{\text{ideal}}$ is the fractional MOLE solute concentration, i is the VAN'T HOFF FACTOR, and M is the molarity (see [Figure O.15](#)).

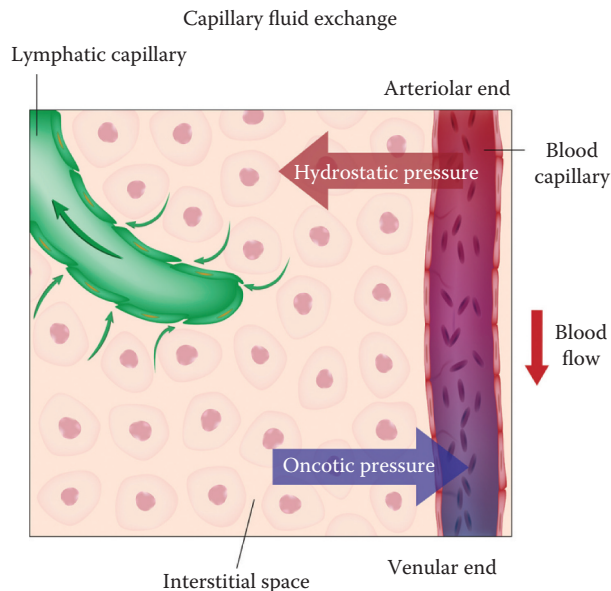


Figure O.15 Oncotic pressure resulting from interstitial fluid solution concentration.

One-dimensional compressible flow

[fluid dynamics] Many of the compressible flows can be modeled as flows through a PIPE, duct or a stream tube for which cross-sectional area changes with relatively small gradual increments in the FLOW direction, relative to the flow velocity. For one-dimensional approximation, there can be no flow components perpendicular to the streamline. Generally, the flow will be steady state. The laws of CONSERVATION OF MASS and momentum apply. The flow conditions under negligible viscous forces are described by the Euler equation: $-(dP/\rho) = v dv$, where P is the pressure, ρ the density, and v the flow velocity. The CONSERVATION OF ENERGY provides the condition that the net change in enthalpy ($H = U + PV$, where U is the internal ENERGY, P is the pressure of the system, and V is the volume) and kinetic energy (E_{kin}) must equal the heat transferred into the control volume and the work done by the FLUID (per unit mass), neglecting work yields: $c_p T + (v^2/2) + dq = c_p (T + dT) + [(v + dv)^2/2]$, where T is the system temperature, c_p is the SPECIFIC HEAT under constant pressure and $q = \dot{Q}/\dot{m}$, where $\dot{Q}$ is the rate of flow and $\dot{m}$ is the change in mass over time.

One-dimensional flow

[fluid dynamics] For incompressible flow, the conditions are very similar to the compressible flow, with the exception that the Euler equation reduces to BERNOULLI'S EQUATION: $(v^2/2) + (P/\rho) = \text{constant}$, where P is the pressure, ρ is the density, and v is the FLOW velocity.

Onnes, Heike Kamerlingh (1853–1926)

[atomic, general, material science, solid-state, thermodynamics] See **KAMERLINGH ONNES, HEIKE**.

A physicist from the Netherlands involved with CRYOGENIC research and the effects of cold temperatures on materials, specifically near the ABSOLUTE ZERO (0 K). Heike Kamerlingh Onnes established the LIQUEFACTION temperature of Helium (${}^4_2\text{He}$) to be at 4.2 K. Kamerlingh Onnes received the Nobel Prize for Physics in 1913 for his cryogenic work. Dr. Kamerlingh Onnes was a colleague and research associate of JOHANNES DIDERIK VAN DER WAALS (1837–1923) during his appointment at the Delft University of Technology. The work of Kamerlingh Onnes provided a great deal of insight into the conditions near absolute zero, which he approached to close degree. His work on cryogenic cooling and the effect it has on materials also offered a new concept: SUPERCONDUCTIVITY.

Onsager reciprocal relations

[thermodynamics] In thermodynamic systems, the Onsager reciprocal relations are used to express the equality of particular ratios between forces and flows that are not specifically in equilibrium; however, local equilibrium may exist under strict boundary conditions. It was introduced by the Norwegian scientist Lars Onsager (1903–1976) in 1931.

Opaque

[general, solid-state] Not transparent, material property.

Open channel

[fluid dynamics] Flow conditions for a system consisting of a conduit with a free surface. A free surface is where a FLUID has zero parallel shear stress and is simultaneously subject to constant perpendicular normal stress. Examples of free surface are the boundary between two homogenous fluids, such as the liquid–water interface with the AIR in the Earth's ATMOSPHERE. This applies, for instance, to channel FLOW (see [Figure O.16](#)).



Figure O.16 Open channel.

Open channel, Bazin equation

[fluid dynamics] Equation for deriving the average flow velocity of water flowing in an OPEN CHANNEL, proposed by Henry E. Bazin (1829–1917) in 1897 (finalized after his death by his assistant Henri P. G. Darcy [1803–1858]). There is a close correlation with the CHÉZY'S FORMULA for flow in an open channel, relying on the Chézy discharge coefficient ($C_{\text{Chézy}}$), with relations to the FLOW configurations defined by the hydraulic radius (r_h) and a channel roughness coefficient (k_s), expressed as $C_{\text{Chézy}} = 157.6 / [1 + (k_s / (1/2)r_h)]$. This yields the average velocity (v_{avg}) as $v_{\text{avg}} = C_{\text{Chézy}} \sqrt{i_{\text{slope}} r_h}$, where i_{slope} is the slope of the bedding of the flow system (e.g., the bottom of the river) (see [Figure O.17](#)).



Figure O.17 Open channel flow, wide canal flowing out into the North Sea.

Open channel, Chézy's formula

[fluid dynamics] An empirical formula designed by the French HYDRAULICS engineer ANTOINE DE CHÉZY (1718–1798) in 1775 that relates river flow (Q) to the dimensions of the channel (i.e., the hydraulic radius, r_h) and slope of the water surface (s_{surface}) as $Q = AC_{\text{Chézy}} \sqrt{r_h s_{\text{surface}}}$, where A is the cross-sectional area of the river, and $C_{\text{Chézy}} = 157.6 / \{1 + [k_1 / (r(1/2))]\}$ is the Chézy discharge coefficient.

Open channel, Ganguillet–Kutter equation

[fluid dynamics] An empirical formula designed by the Swiss HYDRAULICS engineers Emile Oscar Ganguillet (1818–1894) and Wilhelm Ruldoph Kutter (1818–1888) in 1869 that relates average river flow velocity (v) to the dimensions of the channel (i.e., the hydraulic radius, r_h) and slope of the water surface (s_{surface} , representing the ENERGY drop) as

$$v = \left\{ \frac{(a + (b/n_K) + (P/s_{\text{surface}}))}{\left[1 + (n_K/\sqrt{r_h})(a + (P/s_{\text{surface}}))\right]} \right\} \sqrt{r_h s_{\text{surface}}},$$

where n_K is the Kutter roughness factor, which is generally between 0.01 and 0.035 for the usual channel bottom surfaces; the value of Kutter's C , to be used with Chézy's formula, ranged from 22 to 220, where $a \sim 41.66$ for uniform channel and $b \sim 1.811$ for uniform channel are coefficients based on the work of Henri E. Bazin (1829–1917) and P represents the hydrostatic pressure. For values of $s_{\text{surface}} > 0.0005$ the term P/s_{surface} can generally be neglected.

Open channel, hydraulic mean depth

[fluid dynamics] The ratio of the cross-sectional area to the surface width. Channels can have many different contour configurations based on the methods in which the channel was dug-out, primarily a V-shape is found (such as the Suez Canal), but over time the shape can change. Other digging mechanism require a more rectangular shape, such as the Panama Canal (see [Figure O.18](#)).



Figure O.18 Locks for the Panama Canal.

Open channel, Manning equation

[fluid dynamics] An empirical formula derived by the Irish engineer ROBERT MANNING (1816–1897) in 1851, that relates river flow (Q) to the dimensions of the channel (i.e., hydraulic radius: r_h) and slope of the water surface (s_{surface}) $Q = (C_{\text{Chézy}}/n) \mathcal{A} r_h^{2/3} i_{\text{slope}}^{1/2}$, where n is Manning's coefficient (accounting for FLOW bed roughness), $C_{\text{Chézy}} = 157.6 / \{1 + [k_1 / (r(1/2))]\}$ is the Chézy discharge coefficient, i_{slope} is the slope of the bedding of the flow system (e.g., the bottom of the river), $\mathcal{A}$ is the cross-sectional area of the river; which translates to an average velocity: $v_{\text{avg}} = (C/n) r_h^{2/3} i_{\text{slope}}^{1/2}$.

Open cycle

[fluid dynamics, thermodynamics] The concept of the open cycle relates to thermodynamic processes but has no physical thermodynamic meaning. The concept refers to the external ENERGY supply to, for instance, an ENGINE in the form of fossil fuel and that the remaining, unconverted portion of energy embedded in the spent combustion mixture, is expelled as exhaust to the environment. THERMODYNAMICS cycles can be divided in two categories: power cycles and heat-pump cycles. The POWER CYCLE produces power output while the heat-pump cycle has a net power consumption. GAS turbines fall under the power cycle and have an open cycle, representing the intake of fresh AIR and the exhaust. Other open-cycle dives are combustion engines. This is different from refrigeration, which is a closed cycle, or cyclic system (see Figure O.19).

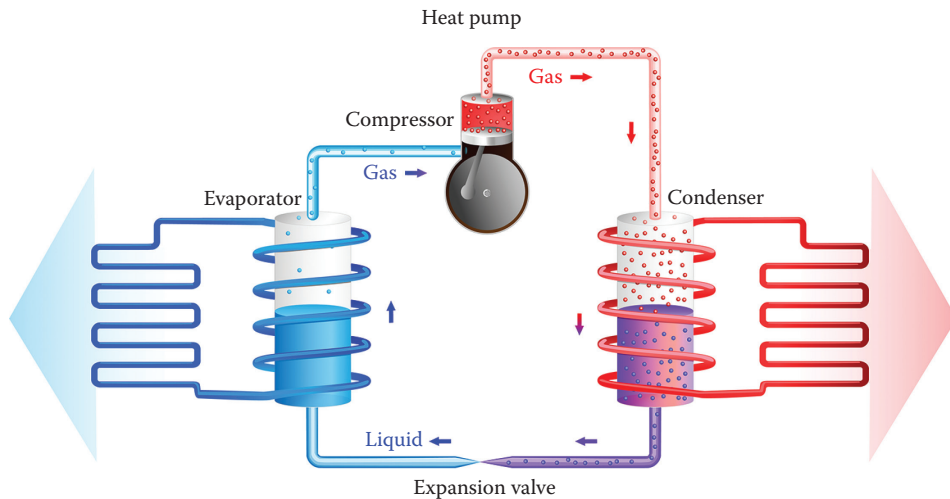


Figure O.19 Example of an open-cycle process: Heat pump cycle diagram.

Open Joule–Brayton cycle

[thermodynamics] A thermodynamic process of combustion, heat ENGINE, or boiler that is per definition open, involving intake and exhaust. The Joule–Brayton cycle is a constant-pressure cycle that defines the operation of the GAS turbine engine (e.g., JET engine and electric power generation). It is named after American engineer George Brayton (1830–1892), although it was originally proposed and patented by English engineer John Barber (1734–1801) in 1791. The involvement of English physicist JAMES PRESCOTT JOULE (1818–1889) added his name to the process. The Joule–Brayton cycle applies to gas turbines only when both the compression and EXPANSION processes take place in rotating process (machine). The Joule–Brayton cycle is a sequence of an ISENTROPIC compression and isentropic turbine. The useful power generated by the TURBINE is the difference between the compression ($P_T = mc_p T_i (1 - (1/\delta)^{(\kappa-1)/\kappa})$, where κ is the SPECIFIC HEAT ratio, δ is the pressure drop at the outlet, m is the mass of the combustible, c_p is the specific heat under constant pressure, and T is the temperature) and turbine ($P_T = m\Delta h = mc_p \Delta T$, where h the specific enthalpy): $P = P_T - P_C$, also known as either “Brayton cycle” or “Joule cycle.”

Open MRI

[biomedical, imaging] Magnetic RESONANCE imaging system that has a configuration with large bore access, in contrast to the traditional MRI machines that have a narrow cylinder through which the patient is transported on a sliding table during the image-slicing process. Open MRI uses permanent magnets and have lower NOISE than the traditional MRI (see [Figure O.20](#)).

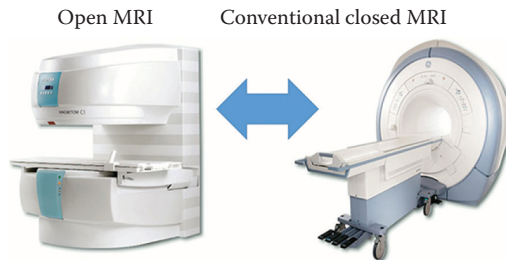


Figure O.20 Comparison of open-design MRI machine versus the conventional closed MRI.

Operational amplifier (OpAmp)

[electronics] A differential input high-gain electronic voltage amplifier, using DC coupling, with usually a single-ended output. By configuring the power supply and the termination impedance ratio across the specific POLES, an output potential can be generated that is hundreds of thousands of times larger than the POTENTIAL DIFFERENCE between the input terminals, the gain, while simultaneously maximizing the signal-to-noise ratio. In contrast, a simple resistor, TRANSISTOR, CAPACITOR, and INDUCTOR circuit can generate amplification, but the NOISE follows suit to the SIGNAL. OpAmps were initially used in analog computers. OpAmps can perform basic mathematical operations, such as multiply, differentiate, integrate, and in turn provide filtering opportunities. The mathematical operations are selected based on the configuration of the electronic peripheral components, a capacitor will provide the basic tools for integration. OpAmps are some of the most widely used electronic devices. OpAmps are found in various and vast amounts of consumer devices as well as industrial and scientific devices. OpAmps are generally based on semiconductor materials; however, George A. Philbrick (1913–1974) introduced a VACUUM tube OpAmp in 1948. Following the birth of the transistor in 1947, the first discrete integrated circuit (IC) OpAmp was introduced in 1961 (see [Figure O.21](#)).

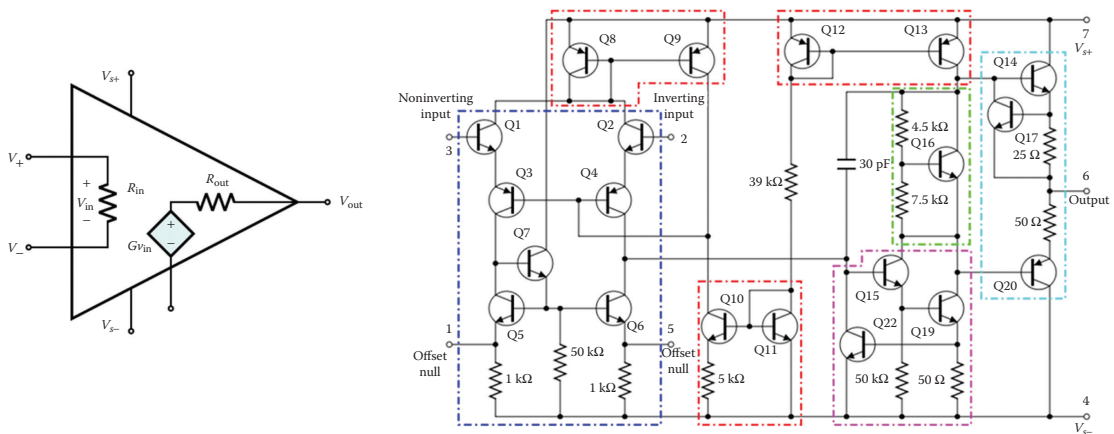


Figure O.21 Diagram of operational amplifier.

Ophthalmology

[biomedical] Medical specialty that focuses on all aspects of the **EYE**, including but not limited to the **ANATOMY**, **PHYSIOLOGY**, and diseases of the eye. This branch of **MEDICINE** provides support for restoration or enhancement of **VISUAL ACUITY**. The specific anatomical components of the eye of interest are the **LENS** shape and functionality, the **RETINA**, signal communications (e.g., optic nerve), and the pathology of the lens, such as cataract, next to diseases to the optic nerve such as glaucoma (see [Figure O.22](#)).



(a)



(b)

Figure O.22 (a,b) Ophthalmologic eye exam.

Oppenheimer, Julius Robert (1904–1967)

[energy, general, nuclear, quantum] A theoretical physicist from the United States. President Roosevelt established the **MANHATTAN PROJECT** in 1941 and appointed Robert Oppenheimer as director in June 1942. The resulting first **ATOMIC BOMB** was detonated in new Mexico under his guidance on July 16, 1945, followed by two atomic bomb drops on Japan in July and August. Oppenheimer was one of the first scientist to predict the existence of **ANTIMATTER** based on theoretical analysis (see [Figure O.23](#)).



Figure O.23 Julius Robert Oppenheimer (1904–1967). (Courtesy of the Los Alamos National Laboratory, Los Alamos, NM, in 1943.)

Optical activity

[biomedical, chemical, optics] Rotation of polarization ANGLE of ELECTROMAGNETIC RADIATION induced by large complex molecules (chiral molecule), first observed in liquids and gases by JEAN-BAPTISTE BIOT (1774–1862). Two kinds of rotation can be distinguished: dextrorotary (clockwise rotation) designated as (+) and levorotary (rotate counterclockwise) designated as (–). Dextrose will generally rotate the polarized light clockwise, whereas fructose is a levorotary solution. Naturally occurring in milk, dextro-lactic ACID is a food, whereas artificially produced laevo-lactic acid is a poison (in actuality, left-turning lactic acid does occur in natural form however in extremely small percentage). The rotation of linearly polarized light by solid media was first observed by French physicist FRANÇOIS JEAN DOMINIQUE ARAGO (1786–1853) in 1811 in QUARTZ (see [Figure O.24](#)).

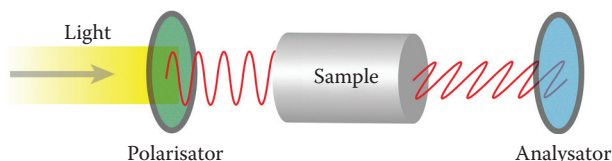


Figure O.24 Optical activity, such as would be experienced with glucose solution.

Optical attenuation screening for concentration

[biomedical, imaging, optics] Optical attenuation imaging method for determination of molecular separation while applying the ULTRACENTRIFUGE principle. The chromophores in the SOLUTE will absorb the incident ULTRAVIOLET or visible light and the density of chromophores is a direct indication of concentration due to the symmetric outline of the sample cell/ampule. The concentration is plotted as a function of location in the vial (also *see* CHROMATOGRAPHY and GAS CHROMATOGRAPH) (see [Figure O.25](#)).

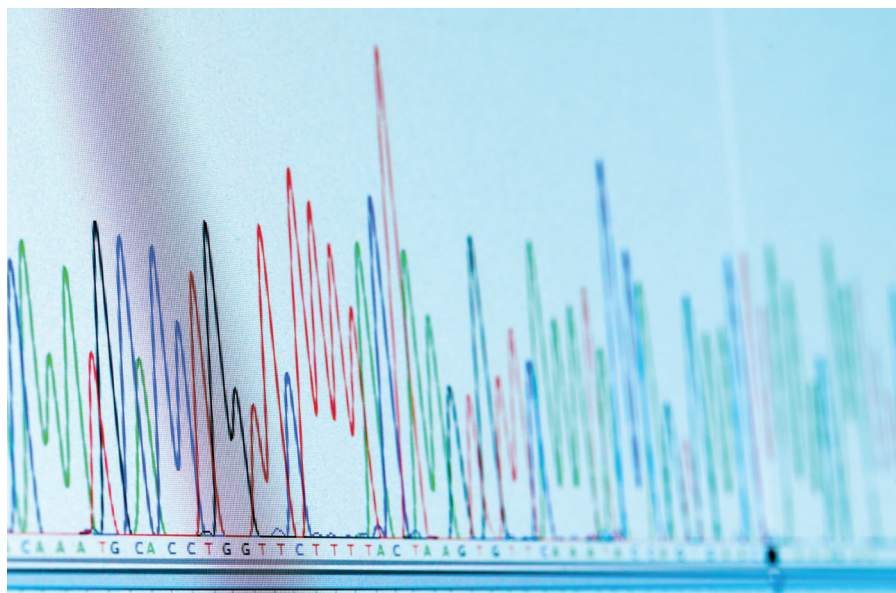
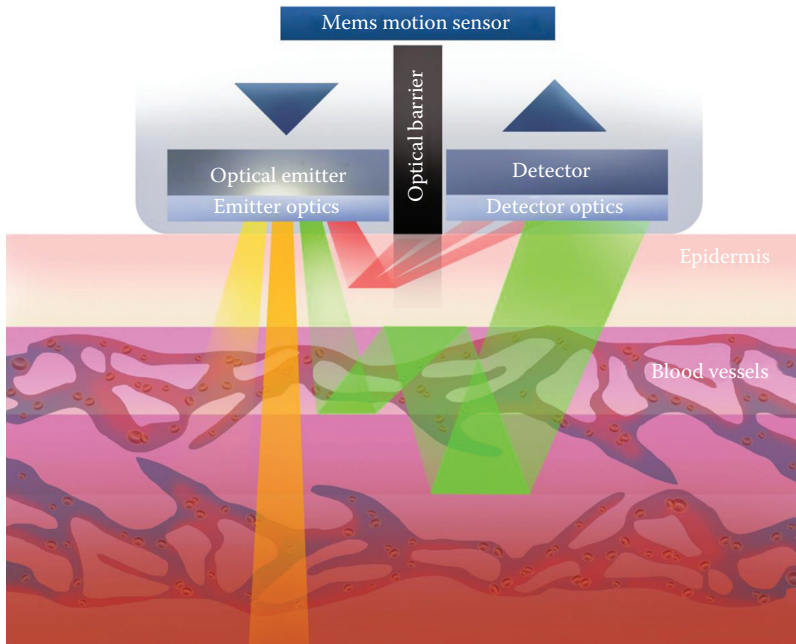


Figure O.25 Chromatography spectral representation of chemical composition for DNA (deoxyribonucleic acid).

Optical biosensor

[biomedical, optics] Biometric sensors that rely on optical interrogation the determination of physiological parameters. One specific example is the attenuation determination of a minimum of two wavelengths for

BLOOD oxygen saturation in the application pulse oximetry. In pulse oximetry, the use of additional wave-lengths can eliminate errors resulting from biological variability in blood or surrounding tissues. Additionally, use of OPTICAL ACTIVITY has been applied to the determination of blood GLUCOSE levels with respect to diabetic patients, measured in the EYE (*also see* PULSE OXIMETRY) (see [Figure O.26](#)).



(a)



(b)



(c)

Figure O.26 (a) Optical biosensor using the back-scattered light to gain information about spectral signatures of chemical constituents (e.g., pulse oximetry [b]) and periodically changing events such as blood flow associated with heart pump rate (i.e., heart rate [c]).

Optical coherence tomography

[imaging, optics] Optical scanning imaging technique using interferometry to selectively collect light from axial locations at various depths from the surface used for tomographic IMAGE reconstruction. The general concept of optical coherence tomography (OCT) is very similar to B-SCAN ultrasound in the fact that point-by-point “intensity” data is collected for within a three-dimensional structure. The imaging principles of OCT rely on scanning the device across the surface of the volume of interest, without actually requiring

contact, as well as probing the surface location by changing the boundary conditions for the scanning device by optical and mechanical means. A two- or three-dimensional image reconstruction follows after all the required data points within the medium under investigation are collected, stored in a location specific matrix and processed for specific electromagnetic features contained in the optical signal. The main electromagnetic features are AMPLITUDE of the electric and MAGNETIC FIELD, the PHASE of the wave, the orientation of the electric field (POLARIZATION) as well as wavelength specific information. Since the wavelength of light is very small with respect to the scanning range, the phase of the WAVE becomes essential in isolating the relevant information in radiance with respect to the location of interest. Interference will provide a maximum intensity in the SIGNAL collected by a PHOTODETECTOR when the phase of the wave returning from an object under investigation matches the phase of a wave returning from a reference MIRROR in the balancing arm of the INTERFEROMETER. Consider a MICHELSON INTERFEROMETER, with a probing arm and reference arm that are the result of splitting the light from a source in two directions. Once the light returns from the probing arm and reference arm, it is recombined and the superposition principle applies to the two wave-phenomena that is measured by the photocell in the measurement arm. The INTERFERENCE signal in the measurement arm is maximal when the probing arm length matches the reference arm length. This interference pattern is repetitive in increments of the wavelength of the incident light from the source. For a MONOCHROMATIC LIGHT source, this makes the identification of the secondary source location inside the medium being investigated not uniquely defined, because the interference will occur at every wavelength DISTANCE with equal MAGNITUDE. When a broadband source is used, rather than a laser, the interference pattern of all the wavelengths in the spectral distribution of the source will need to coincide for maximal signal magnitude in the measurement arm. The use of a broadband optical source provides the critical aspect for depth resolved imaging under OCT. The advantage of optical imaging is that it can provide high RESOLUTION media-interrogating imaging (better than X-RAY, magnetic RESONANCE imaging, or ULTRASOUND) and it can be performed in situ using hand-held devices, specifically under in vivo conditions for biological imaging. The use of optical imaging also has no concerns for side effects, and light can penetrate deep into turbid media. The concept of OCT was developed at the Massachusetts Institute of Technology (MIT) under the lead of Dr. James G. Fujimoto (mid twentieth century), with team members Carmen A. Pulliafito (mid twentieth century), Eric A. Swanson (mid twentieth century), and David Huang (mid twentieth century) in the late 1980s. The fact that most media and solid objects have light SCATTERING properties, the loss of light due to scattering before returning to the point of introduction at the surface for collection and process provides significant reduction in signal strength. The impact of scattering on the signal quality in the optical interrogation of turbid media places significant constraints on the imaging modality. On the positive side, the in-site high-resolution imaging can be performed under relatively low instrument cost. The OCT technology does not require expensive high-powered laser sources and can be used in FIBER-OPTIC mode or free-space. OCT has an axial resolution of better than $3\text{ }\mu\text{m}$ and lateral in the order of μ , with depth of probing exceeding 3 mm. The depth resolution is a function of the coherence length of the broadband source. The LATERAL RESOLUTION is a function of the device dimensions, specifically the tip diameter of the fiber-optic probe. The depth resolution is directly proportional to the coherence length, where the coherence length (L_c) is defined by the bandwidth ($\Delta\lambda$) of the source with respect to the central wavelength (λ_0): $L_c = (2 \log 2 / \pi) (\lambda_0^2 / \Delta\lambda)$. For a super-luminescent DIODE, the bandwidth is in the order of $\Delta\lambda = 32\text{ nm}$ with inherent resolution $\text{Res}_{\text{ax}} = 10\text{ }\mu\text{m}$, alternatively a MODE-LOCKED LASER will provide $\Delta\lambda = 350\text{ nm}$ with inherent resolution $\text{Res}_{\text{ax}} = 1.5/n\text{ }\mu\text{m}$, n the index of REFRACTION of the medium. The bandwidth of the pulse laser is defined by the pulse width (Δt) as $\Delta\nu\Delta t \geq 1/(4\pi)$, $\nu = c/\lambda$ the frequency of the ELECTROMAGNETIC RADIATION and c the speed of light. The probing mechanism of the OCT is not a stationary process. In order to provide accuracy about the true maximum signal strength at the balance interferometer depth in the medium a process called “heterodyning” is applied, providing a perturbation around the equilibrium position. Heterodyning ensures the isolation of the exact magnitude of positive interference for all wavelengths in the wave package from the broadband source. By changing the length in the reference arm on a fixed periodic interval (with angular frequency ω_h ; frequency ν_h), the acquired signal from the equilibrium depth will fluctuate over time in depth. The source signal is modulated by frequency $\nu_{h,1}$ and the detected signal will be modulated at frequency $\nu_{h,2}$ which yields the interference signal at the detector: $\Psi(t) \propto A^2(t) = (A_{1,0}^2/2) + (A_{2,0}^2/2) + A_{1,0}A_{2,0} \cos(2\pi[\nu_{h,1} - \nu_{h,2}]t) \propto \text{Voltage}(t)$ with $A_{i,0}$ the respective electric field amplitude in the reference

signal and sample signal. The modulation of the detection (sample) signal provides a mechanism of phase-locked detection (similar to what is applied in RADIO receivers). This interference signal fluctuates with the BEAT FREQUENCY (ν_b) with respect to the two modulations. The heterodyning provides a significant increase in the signal-to-noise ratio, better than 140 dB. The envelope of this signal contains the information pertaining to the three-dimensionally defined location inside the medium to be used for tomographic image reconstruction. Additionally, the path-difference between the reference arm of the interferometer and the sample arm introduces a time delay: $\tau_{\text{interferometer}} = (L_1 - L_2)/c = (d_{\text{diff}}/c)$ which influences the “visibility” of the interference fringe. The fringe “intensity” is a function of the spectral bandwidth and the path difference as $S(\tau_{\text{interferometer}}) = \int_{\nu_{\min}}^{\nu_{\max}} S(\nu) [1 + \cos(2\pi\nu\tau_{\text{interferometer}})] d\nu$. This in turn translates into a visibility function for the fringe that is the relative difference between the minimum intensity and the maximum intensity: $V_{\text{vis}}(\tau) = [(S(\tau)_{\max} - S(\tau)_{\min}) / (S(\tau)_{\max} + S(\tau)_{\min})] = S_0 \{1 + U(\tau) \cos[2\pi\nu_0\tau + \phi(\tau)]\}$, where $\phi(\tau)$ is the phase shift, and $U(\tau) = \exp(-(d_{\text{diff}}/L_c))$ is the envelope of the heterodyne function. With this algorithm, very accurate and sensitive measurements of the localized optical parameters can be performed, thus identifying the medium based on documented reference table of optical parameters and optical effects. Using all the electromagnetic properties various types of OCT devices have been developed, in combination with specific computational techniques: POLARIZATION sensitive, phase resolved, spectroscopic, time-domain, DOPPLER, and Fourier domain. Each respective technique can provide certain particulars about the medium under optical interrogation. The most well-known imaging applications for OCT are for the RETINA of the EYE. Additional application are also found in the intestines by means of endoscopic probing, as well as the investigations of SKIN with respect to for instance stage and spread of cancer growth. The imaging modalities are still relatively confined to surface applications (see Figure O.27).

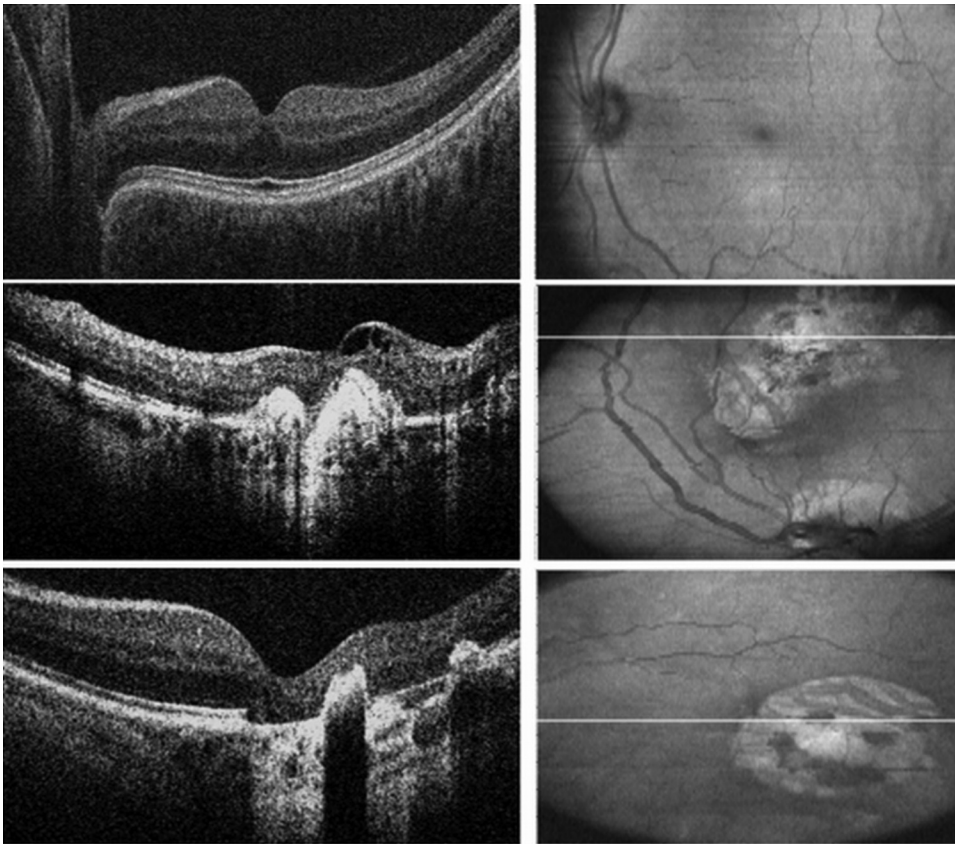


Figure O.27 Optical coherence tomography image. (Courtesy of the Bioptigen, Raleigh, North Carolina.)

Optical density (OD)

[general, optics] Optical attenuation quantity that uses the LOGARITHM of the value for the attenuated radiance with respect to the incident light for a specific optical component and is not referenced against the thickness of the medium: $OD = -\log_{10} T$, where T represents the transmission of light in standard units, usually determined in derived unit of “voltage” based on the sensor unit, detection mechanism and SIGNAL acquisition. The optical density of a medium will be a function of wavelength and has no units.

Optical magnification

[biomedical, engineering, general, optics] Two types of magnification can be distinguished: angular magnification and lateral magnification. Lateral magnification is the ratio of the size of the IMAGE (i) to the object size (o): $M_{\text{mag}} = -(i/o)$, where the sign indicates the relative orientation of the image with respect to the object. Angular magnification indicates the observed size by the EYE based on the ANGLE that the object subtends to the eye, where the angle is measured with respect to the optical axis: $M_{\text{mag}} = \theta/\theta_N$, where θ_N is the relative angle from the NEAR-POINT of the eye ($\sim 0.25m$): $\theta_N = b/0.25m$, with b the “height” (vertical length) of the object, and θ the angle at which light rays enter the eye (using the rays originating from the edges for maximum value) (see [Figure O.28](#)).

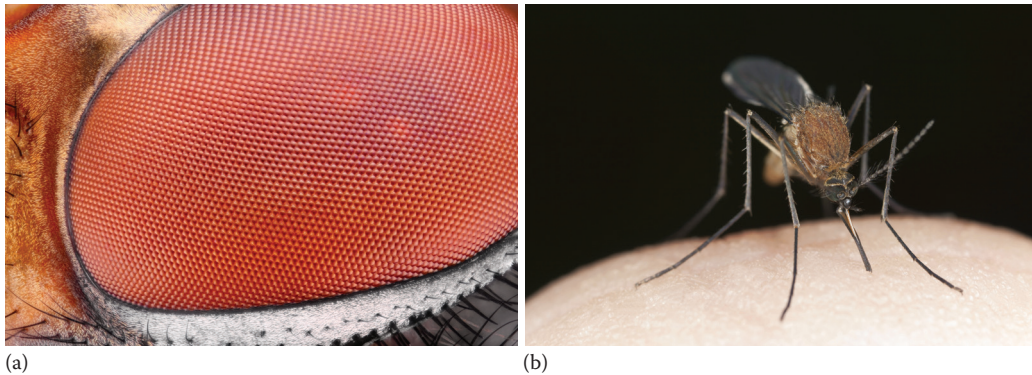


Figure O.28 (a,b) Magnified view of insect compound eye.

Optical path length (O.P.L.; D)

[biomedical, general, optics] The average DISTANCE light can travel in a turbid medium before it is annihilated between SCATTERING interaction and absorption, based on a PROBABILITY distribution of the relative

proportions for both events: $D = 1 / [\mu_a + (1 - g)\mu_s]$, where μ_a is the ABSORPTION COEFFICIENT, μ_s is the SCATTERING coefficient, and g is the scattering anisotropy factor (see Figure O.29).

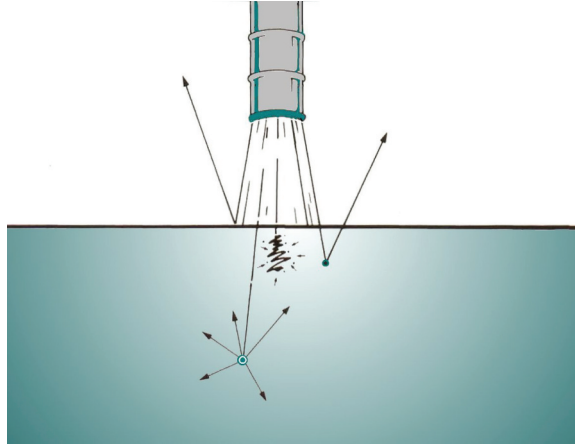


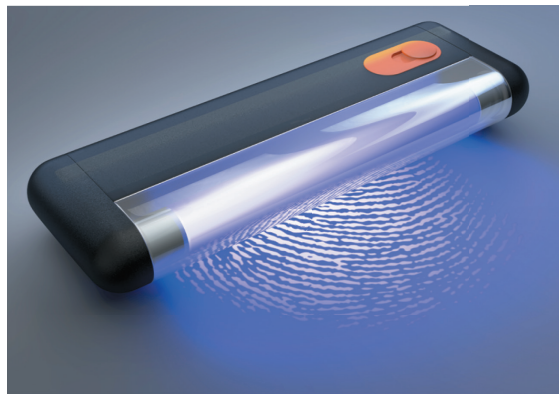
Figure O.29 Representation of five photons traveling in a turbid medium until each respective photon is finally absorbed or leaves the medium through backscatter. The optical free path for air is virtually infinite, providing blue-skies and red sunsets.

Optical sensing

[electromagnetism, optics, theoretical] Any mechanism that relies on light or ELECTROMAGNETIC RADIATION as the means to derive a physical property of a medium or a biological specimen. The detection mechanism will use a sensor unit that converts the quantity of light (i.e., fluence or radiance) in an electric SIGNAL for further processing. Detection can be performed by a variety of photoelectric devices; pin diodes, solar CELL, PHOTO-MULTIPLIER TUBE, DIODE as well as chemical and mechanical devices such as the ELASTOMER polydimethylsiloxane (PDMS, a pressure sensor polymer). One specific application of optical sensing is in character recognition, retinal scans and the like, based on a two-dimensional pattern of light and dark (see Figure O.30).



(a)



(b)

Figure O.30 (a) Optical fingerprint recognition using ultraviolet light and (b) to detect the greasy imprint of the pattern of ridges on the fingertip.

Optical spectra

[optics] The wavelength content of the collected light after interaction with a medium, generally resulting from a broadband LIGHT SOURCE. There are several kinds of spectra that can be distinguished based on the manner it is created or the mechanism of action involved in the formation of the emitted LIGHT. Two kinds of spectra are recognized: ABSORPTION and EMISSION. The emission spectra, for instance, is the creation of light from a high TEMPERATURE SOLID, liquid, or dense gas, which will be continuous, whereas a low pressure GAS will emit a LINE or BAND spectrum. An ABSORPTION SPECTRUM will display gaps representative of the ELEMENTS in the exposed medium. Specific spectral analysis techniques are available to retrieve specific details about the light-matter interaction. The specific light interaction on a molecular or atomic level can provide identification mechanisms for the presence and volumetric MAGNITUDE of chemical constituents. Molecular spectra can be recognized based on ELECTRON SPIN states (specifically electron paramagnetic resonance), molecular VIBRATION, molecular rotation, atomic scissor-action within the MOLECULE, as well as electronic states. Specific spectroscopic analyses include, for instance, Raman spectroscopy, vibrational circular dichroism spectroscopy, hyperspectral imaging, and laser-induced breakdown spectroscopy (see [Figure O.31](#)).

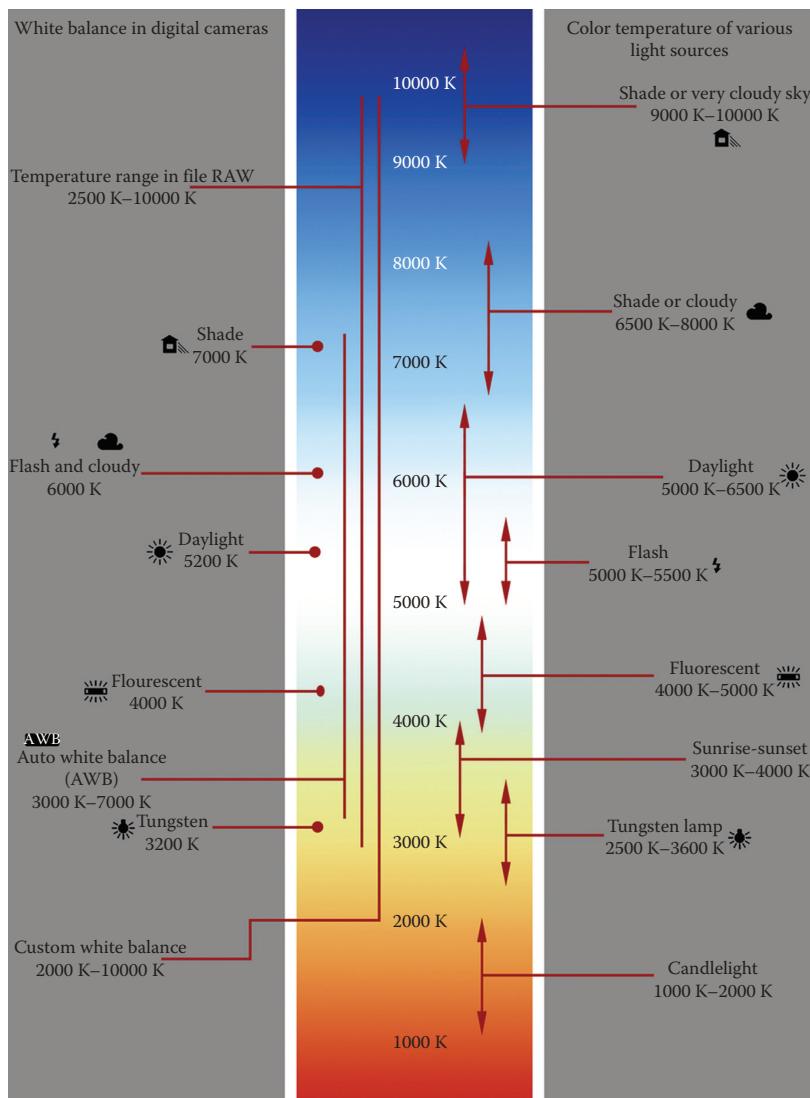


Figure O.31 Chart representing color temperature, broad spectral emission from solids.

Optically dense

[optics, solid-state] Solid, liquid, or gas that has a molecular separation that is smaller than the wavelength of the light incident on the medium. For both solids and liquids, the molecular spacing is of the order of 20–30 nm. For gases, the conditions under standard temperature and pressure yield on average a separation of 300 nm. Under all of these circumstances, the internal electric field may be associated with a DIPOLE. The molecules in suspension experience an electric external field, such as the ELECTROMAGNETIC RADIATION, as well as a secondary field produced by neighboring molecular dipoles. The external field produce an OSCILLATING DIPOLE moment with associated RADIATION. This entails that the molecules in an optically dense medium will be coupled. The net result of electromagnetic (EM) radiation interaction with an optically dense medium is a superposition of the molecular interaction with the incident WAVE. The re-emitted wave can in bulk be described by either Mie or RAYLEIGH SCATTERING theory, depending on the respective wavelength ranges. At the interface between two media with a large quantity of homogeneously distributed molecules, the presumably randomly re-emitted light converts on average into SNELL'S LAW for the refracted light.

Optics

[general] Scientific discipline that investigates and utilizes ELECTROMAGNETIC RADIATION, primarily the visible spectrum, but not limited to that. Optics deals with REFRACTION, diffraction, reflection, IMAGE formation, LENS design, spectral analysis and general ENERGY transfer, FLUORESCENCE, as well as general atomic and molecular interactions. Optics investigates both the PARTICLE aspect of photons as well as the WAVE property. Optics is also engaged with the design and development of physical detection mechanisms available for diagnosing and quantifying electromagnetic radiation and its sources. Most optical interactions can be described on a rigorous level with MAXWELL EQUATIONS. The interaction of light rays at an interface can be described by geometric optics, applying laws of refraction and reflection on rays representing the path of photons. Physical optics applies to a more comprehensive model of light, including the wave phenomena, explain experiences such as diffraction and INTERFERENCE that cannot be accounted for using geometric optics. Most optical phenomena can be accounted for using a classical electromagnetic description, however, phenomena that rely on both the wave and particle properties requires a QUANTUM mechanical approach. Historically optics can be traced back as far as the ancient Egyptians and Mesopotamians in 700 BC, for their use of lenses made from polished crystal, often QUARTZ. The development of the MICROSCOPE formed an important breakthrough in 1595 by HANS JANSEN (sixteenth century, no exact dates), next to the design of the refracting TELESCOPE in 1608 by HANS LIPPERSHEY (1570–1619). Up to the proposition of the wave

theory of light by CHRISTIAAN HUYGENS (1629–1695) in 1690, the ray (corpuscular) theory of light prevailed. Visual perception (VISION) forms a small but important aspect of optics (see Figure O.32).

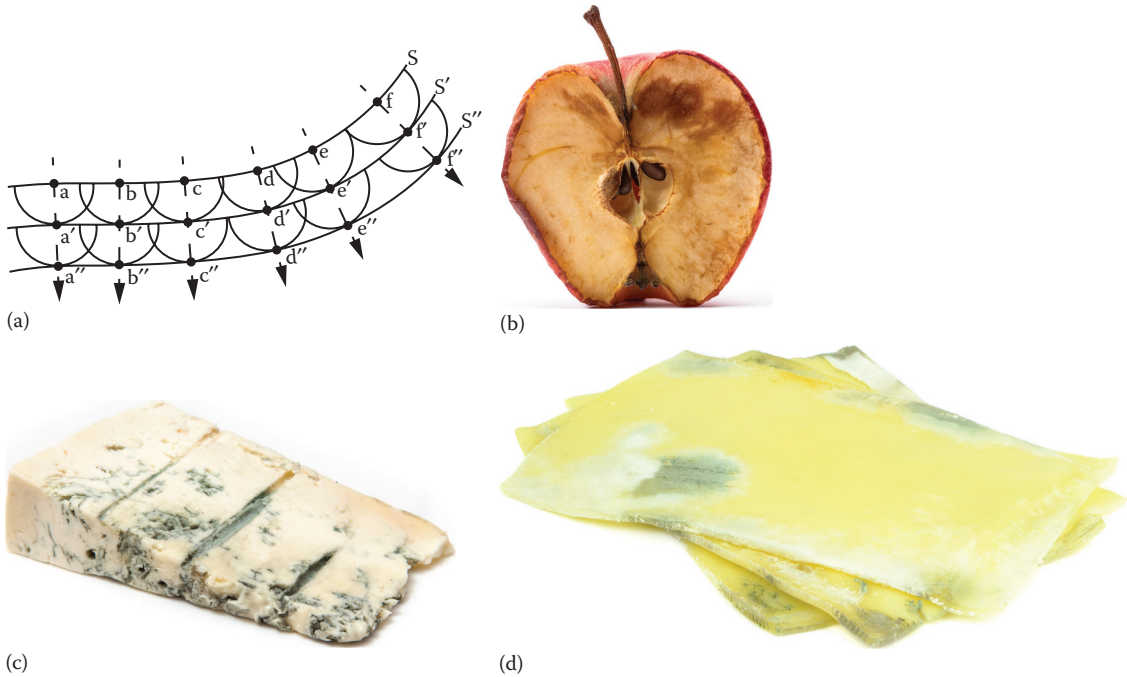


Figure O.32 (a) Huygens wavefront. The eye also performs an optical inspection, which is spectrally interpreted by the brain, warning the consumer about (b) rotten fruit or (c,d) moldy cheese.

Optoacoustic imaging

[optics, thermodynamics] See PHOTO-ACOUSTIC IMAGING.

Orbital angular momentum

[atomic, nuclear] Property that may refer to either electromagnetic waves or a QUANTUM MECHANICS angular momentum operator. In general classical mechanics, the operator for the angular momentum is the cross product of the direction ($\vec{r}$) and the moment ($\vec{p} = m\vec{v}$): $\vec{L} = \vec{r} \times \vec{p}$. For a body (of any shape) rotating around a central axis the body will be constructed of a finite number of mass ELEMENTS with respective angular momenta that are linked to the MOMENT OF INERTIA of these respective elements (combining to the rigid body): I , as $L = M_0 v_t r$, with v_t the tangential component of the velocity, M_0 the mass of the PARTICLE at orbit radius r . Under the condition of no torque resulting from central force, alternatively: $L = I\omega$, where ω is the ANGULAR VELOCITY. On an atomic level, the angular momentum will describe the orbits of ELEMENTARY PARTICLES and the description will require a quantum mechanical approach. In case the potential ENERGY for the atomic structure depends only on the DISTANCE $\vec{r}$, the WAVE EQUATION can ultimately be solved and separated to yield the angular component. In classical mechanics, the angular momentum will always be conserved due to the absence of external torque. Under quantum-mechanical approach the orbital angular momentum for a particle subject to a central potential will have EIGENVALUE solutions. In a spherical coordinate system (r, θ, ϕ), the various components of the orbital angular momentum can be derived from the respective operator; $L_{op}^2 = L_{x,op}^2 + L_{y,op}^2 + L_{z,op}^2 = -\hbar^2 \left[(1/\sin \theta)(\partial/\partial \theta)(\sin \theta(\partial/\partial \theta)) + (1/\sin^2 \theta)(\partial^2/\partial \phi^2) \right]$, which does not depend on r ; where $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ Planck's constant. The z -component: $L_{z,op} = (\hbar/i)(\partial/\partial \phi)$. The ensuing angular momentum now becomes: $L = \hbar\sqrt{\ell(\ell+1)}$, where ℓ is the orbital angular momentum quantum number, which stands in contrast to the classical mechanics Bohr angular

momentum: $L_z = m\hbar$, now obsolete for atomic MOTION. Note that the z -component still satisfies the Bohr equivalent as $L_z = m\hbar$, where m is other quantum number characterizing the spherical harmonic functions as solutions to the SCHRÖDINGER EQUATION with wavefunction $\psi_{n,\ell,m}$, where n is the primary quantum number. The PARITY of the wavefunction is dependent only on the angular part of the function. The parity of the harmonic oscillator indicates the symmetry or antisymmetry of the WAVEFUNCTION: $\psi_{n,\ell,m} = \psi_{n,\ell,m}(-x)$, or respectively $\psi_{n,\ell,m} = -\psi_{n,\ell,m}(-x)$, and is defined by the ORBITAL ANGULAR MOMENTUM QUANTUM NUMBER (ℓ) as $Parity = (-1)^\ell$.

Orbital angular momentum quantum number (ℓ)

[atomic, general, nuclear] Integer characterizing the spherical harmonic functions of the atomic wavefunction, defined as one of the QUANTUM numbers. In solutions to the SCHRÖDINGER EQUATION ($H\psi = E\psi$), the wave functions ψ are obtained, which describes the PROBABILITY of finding electrons at certain ENERGY levels within an ATOM. The WAVE functions for the electrons are called “atomic orbitals.” The electrons in an atom are described by four quantum numbers. The first three quantum number are specifying the particular orbital of interest (PRINCIPAL QUANTUM NUMBER n , angula quantum number ℓ , and MAGNETIC QUANTUM NUMBER m_ℓ), while the fourth specifies how many electrons can occupy that orbital (spin quantum number m_s), also referred to as “azimuthal quantum number” (see [Figure O.33](#)).

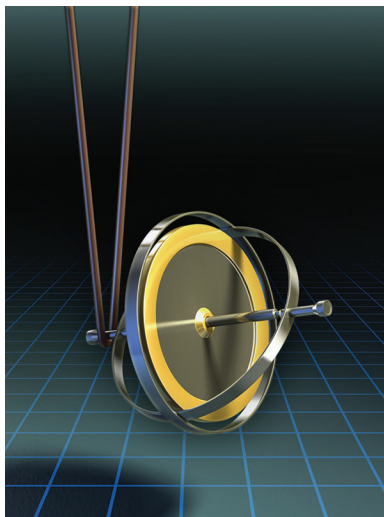


Figure O.33 Orbital angular momentum of a spinning top providing the torque to allow the top to hang at an angle with a suspension sling (i.e., gyroscope effect).

Orbital magnetic moment

[atomic, nuclear] Quantum number used to define the orientation in space of an electron orbit of a given ENERGY (n) and shape (ℓ). The QUANTUM number subdivides the SUBSHELL into individual orbitals; each subshell holds respective electrons, with $2\ell + 1$ orbitals in each subshell.

Orbital magnetic quantum number (m_ℓ)

[general] Quantum number defining the orientation in space of an orbital for a given ENERGY (n) and shape (ℓ); $m_\ell = -\ell, \dots, 0, \dots, \ell$. A sphere ($\ell = 0$) can only be oriented in one way in space. On the other hand, orbitals that have different shapes, such as polar ($\ell = 1$) or cloverleaf ($\ell = 2$), can have an orientation in different directions. A third quantum number is therefore needed to define the orientation in space of the orbital. The MAGNETIC QUANTUM NUMBER is named this way since the different orientations of orbitals were first observed under the influence of an external magnetic field. This QUANTUM NUMBER is one of three

coordinates that result from solving the Schrödinger wave equations, providing the principal (n), angular (ℓ), and magnetic (m_ℓ) quantum numbers. These quantum numbers describe the size, shape, and orientation in space of the orbitals on an ATOM. In contrast to the Bohr model, which is a one-dimensional model that only uses one quantum number to describe the size with respect to the distribution of electrons in the atom. This quantum number subdivides the SUBSHELL into individual orbitals which hold the electrons; there are $2\ell + 1$ orbitals in each subshell. In this light, the s subshell has only one orbital, subsequently the p subshell has three orbitals, ensuing for the following ELECTRON SHELLS.

Orbital quantum number, (ℓ)

[high-energy, nuclear, quantum, solid-state] See ORBITAL ANGULAR MOMENTUM QUANTUM NUMBER.

Orbital velocity

[computational, fluid dynamics, mechanics, thermodynamics] There are three specific cases of orbital velocity: the speed of a body in orbital under the influence of a GRAVITATIONAL FIELD; the velocity pattern of MOTION of particles in WAVE MOTION, in particular in water and wind waves; the equivalent SCHRÖDINGER WAVE EQUATION velocity of a bound electron required to maintain its orbital kinetic ENERGY. Generally, the orbital velocity describes a balance in two forces, yielding a tangential velocity, and angular velocity (see ANGULAR VELOCITY) (see Figure O.34).

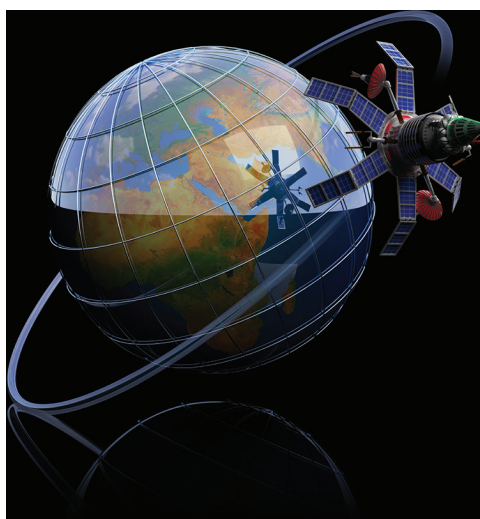


Figure O.34 Concept of orbital velocity for geosynchronous telecommunication satellite.

Orbits

[general] Revolution of an object (man-made or natural) moving in a pattern around another celestial body. The EARTH is in orbit around the Sun. Near-circular orbits are called “Keplerian.” Satellites revolve by remaining in a fixed location with respect to the earth’s geometry, so that we do not have to adjust the (dish-) ANTENNA aimed at the SATELLITE used for television reception. The fixed location with respect to Earth refers to the fact that the satellite is in the GEOSYNCHRONOUS ORBIT or GEOSTATIONARY ORBIT. Spy satellites and weather satellites, on the other hand, are moving around in variable or predetermined patterns, scanning the surface in a grit-pattern. Other forms of orbital motion are equatorial orbit,

graveyard orbit, low Earth orbit, medium Earth orbit, MOLNIYA ORBIT, polar orbit, subsynchronous orbit, and supersynchronous orbit (*also see* EARTH SATELLITE) (see [Figure O.35](#)).

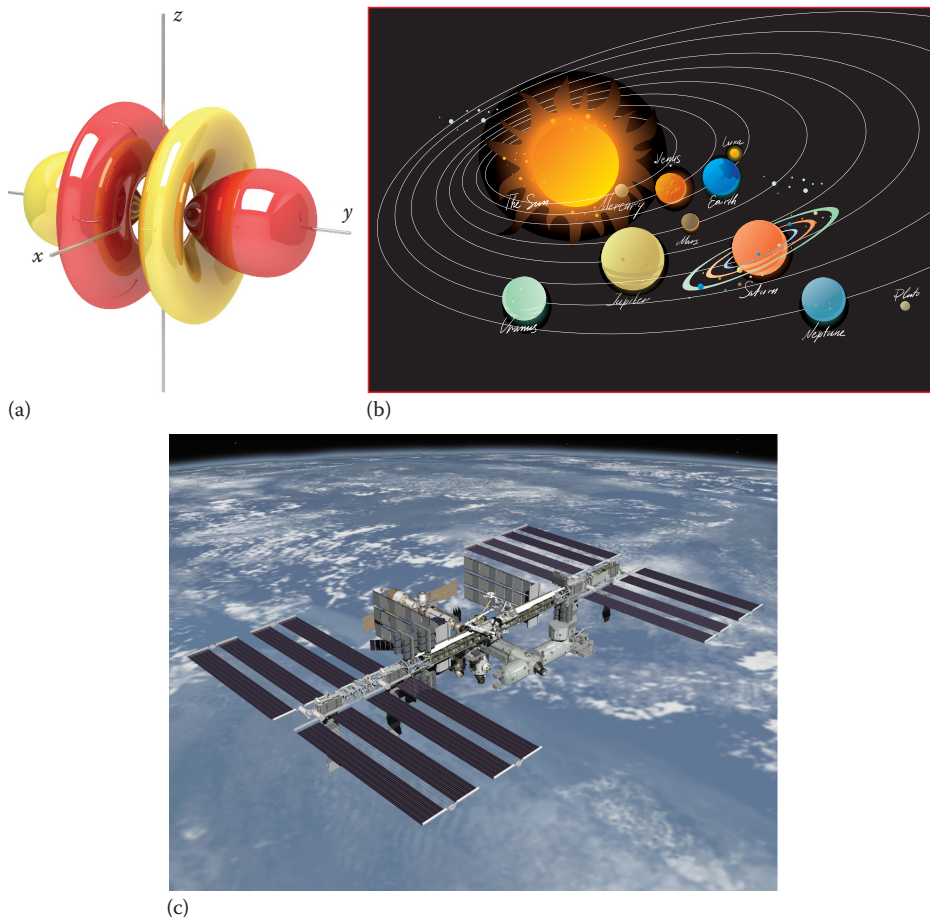


Figure O.35 Examples of orbit: (a) atomic orbit diagram, (b) planetary orbits in our solar system, and (c) a space station in orbit with an approaching space shuttle. (Courtesy of NASA)

Orbits in hydrogen atom

[atomic, nuclear] The COULOMB POTENTIAL for the HYDROGEN ATOM is primarily spherically symmetric and can be defined as a radially dependent function: $V = V(r) = -(Ze^2/4\pi\epsilon_0 r)$, where Z is the charge number, $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron charge, r the DISTANCE to the core, and $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space. The angular momentum operator applied to the WAVEFUNCTION yields a description that is only a function of the radius ($R(r)$): $(1/r^2)(d/dr)[r^2(dR(r)/dr)] + (2\mu_m/\hbar)[E + (Ze^2/4\pi\epsilon_0 r) - (\ell(\ell+1)\hbar^2/2\mu_m r^2)]R(r) = 0$, with SOLUTION $R(r) = G(r)e^{-(r/a_0)}$, where $G(r)$ is the GREEN'S FUNCTION power series truncated to a polynomial (if not, the solution will diverge), $a_0 = 4\pi\epsilon_0\hbar^2/Z\mu_m e^2$ the Bohr first radius ($a_n = n(a_0/Z)$), $\mu_m = m_1 m_2/(m_1 + m_2)$ the REDUCED MASS, m_i the

respective masses of the system, $E_n = -(\mu_m Z^2 e^4 / 32 \pi^2 \epsilon_0^2 \hbar^2 n^2)$, where n is an integer that is greater than the angular quantum number ℓ , $\hbar = h / 2\pi$, $h = 6.62606957 \times 10^{-34}$ m²kg/s Planck's constant (see [Figure O.36](#)).

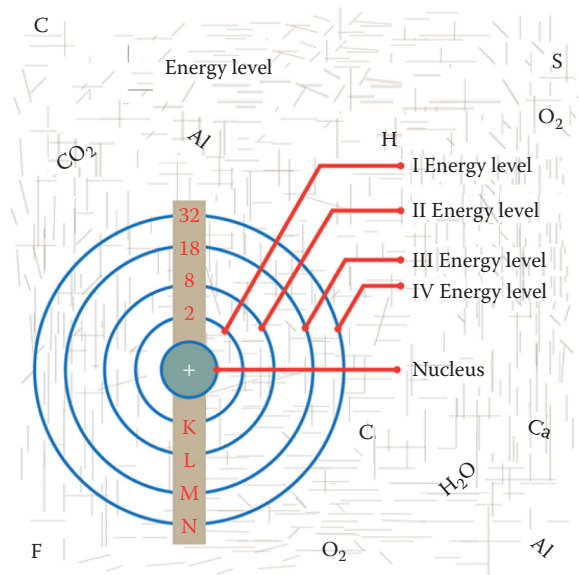


Figure O.36 Energy levels for orbital electron in atoms, including hydrogen.

Orbits of particles in water waves

[fluid dynamics] The WAVE-MOTION of the water surface can in principle be described as a circular MOTION of the individual water molecules (see [Figure O.37](#)).

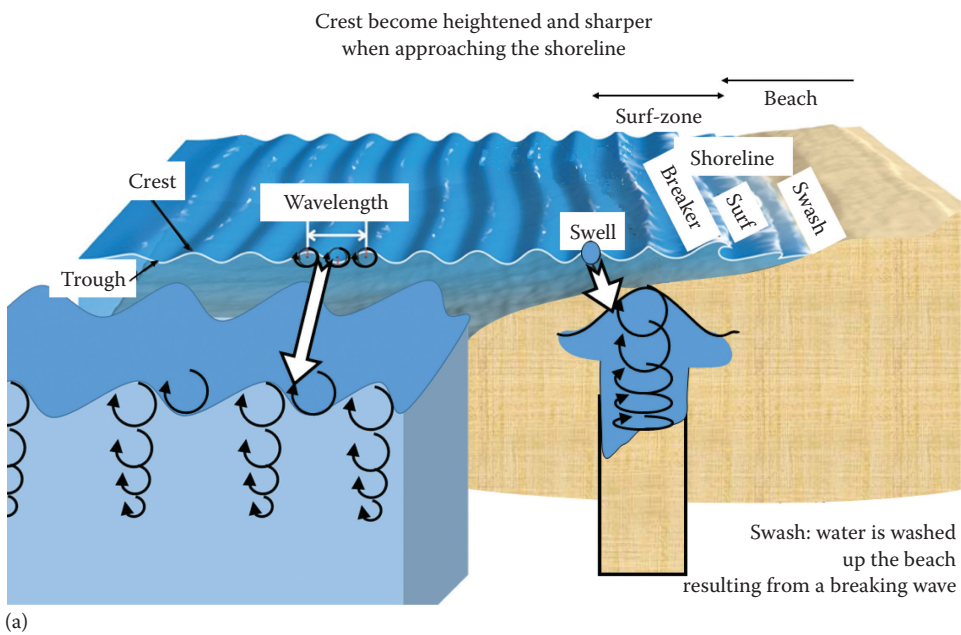
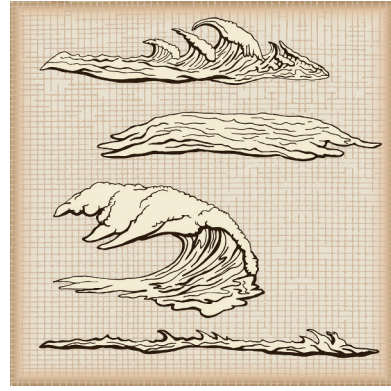


Figure O.37 (a) Diagram of water segments performing orbital motion, with the greatest “amplitude” at the surface. (Continued)



(b)



(c)

Figure O.37 (Continued) (b) "surf" wave, used for "surfing", and (c) types of waves.

Ordinary differential equations

[computational] Mathematical expression describing a function of one single independent variable and the respective derivatives of this variable in various orders, for instance $[dy(t)/dt] = f(t, y(t))$. This stands in contrast to a "partial differential equation," which may include terms with respect to more than one independent variable.

Oresme, Nicolas (1320–1382)

[computational, general] Scientist and philosopher from France, also known as Nicole Oresme, Nicolas d'Oresme, or Nicholas Oresme. Oresme's work provided elementary foundations for the development of advanced mathematics as well as his contributions on the mathematical definitions in science. Oresme is also respected as the greatest medieval economist. Most of his scientific and economic work was based on the elementary work of ARISTOTLE (384–322 BC) (see [Figure O.38](#)).



Figure O.38 Nicolas Oresme (1320–1382).

Organ of Corti

[acoustics, biomedical, electronics, general] Auditory ELEMENT in the cochlea of the INNER EAR. The cochlea has a spiral shape, resembling a snail shell. The organ of Corti is found on the scala-media side on the BASILAR MEMBRANE. The Organ of Corti derived its name from the pathologist Marquis Alfonso Giacomo Gaspare Corti (1822–1876) from Italy who described it. The receptor aspect of the organ of Corti has two types of receptor cells: the inner hair CELL and the outer hair cell. Each of these hair cells have different functions. The organ of Corti contains two rows of rod cells, arranged on the MEMBRANE in the form of a minute arch. To the arch, four rows of hair cells are fixed, consisting of one row on the inner side and three on the outer side. The function of the Organ of Corti is the conversion of SOUND vibrations into nerve pulses. The sound waves are transmitted along the cochlear duct, which form a LONGITUDINAL WAVE that results in the displacement of the tips of the hair, and as such flexing the hair which in turn generates an action-potential. These action-potential impulses are transmitted by the auditory nerve, or cochlear nerve, to the brain, at which location they are interpreted as sound with the frequency associated with the location on the basilar membrane. The detection of long wavelengths are farther into the cochlea (toward the apex), whereas the high frequency are detected close to the entry point at the oval membrane (the base) (see [Figure O.39](#)).

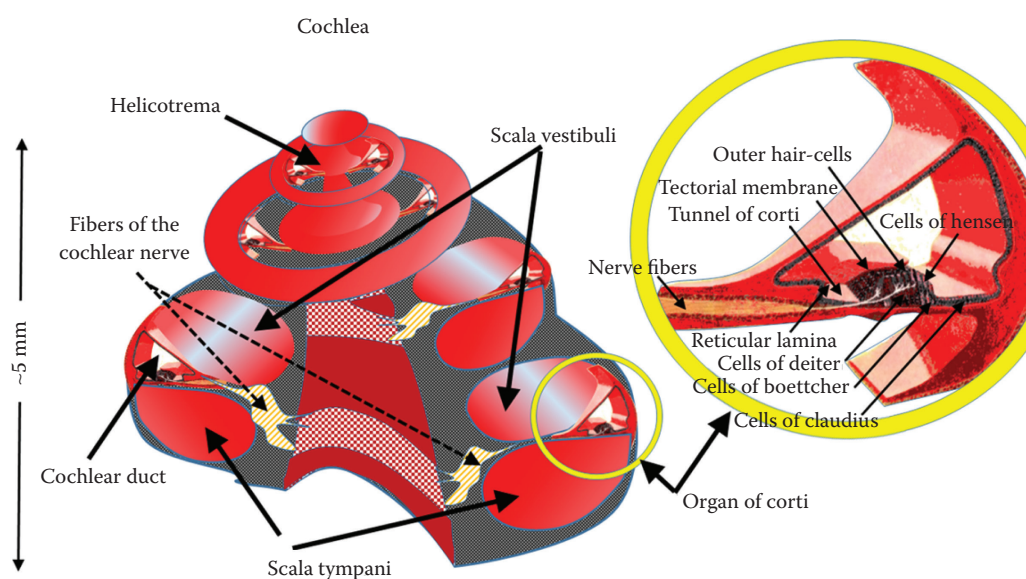


Figure O.39 Organ of Corti, as part of the cochlea, part of the "inner-ear".

Organic scintillator

[nuclear] In NUCLEAR MEDICINE generally there are three types of scintillators: inorganic crystals and organic scintillators next to photomultiplier tubes. Each type of scintillator has the general function of converting ionizing radiation (short wavelength X-RAY; high ENERGY particles), as well as NEUTRON rays, in lower energy photons that can be detected with photocells, photographic film, or the HUMAN EYE. The electronic detection will allow for digital storage, as provided by charge-coupled device array detectors. In inorganic or crystalline detectors, the scintillation mechanism is a direct function of the structure of the crystal LATTICE, using the IONIZATION aspects of energy transfer between selected energy bands. Organic scintillators provide

detection based on the FLUORESCENCE mechanism arises from transitions in the energy levels of a single molecule due to the incident ionizing radiation, no crystalline structure required. Fluorescence is as such detected independently of the physical state of the medium. Organic scintillators are generally composed of aromatic hydrocarbons. An example of an organic scintillator is anthracene as a fluorescent medium. Scintillators are used for X-ray detection (e.g., computed TOMOGRAPHY scan), GAMMA RAY detection, as well as high energy particle PHYSICS. Organic scintillators are generally more useful in high energy X-ray detection and have limited spectroscopic application, depending on the design; primarily, in PARTICLE spectroscopy (neutrons and charged particles). Plasticized organic scintillators have superior response time of a few nanoseconds (see Figure O.40).

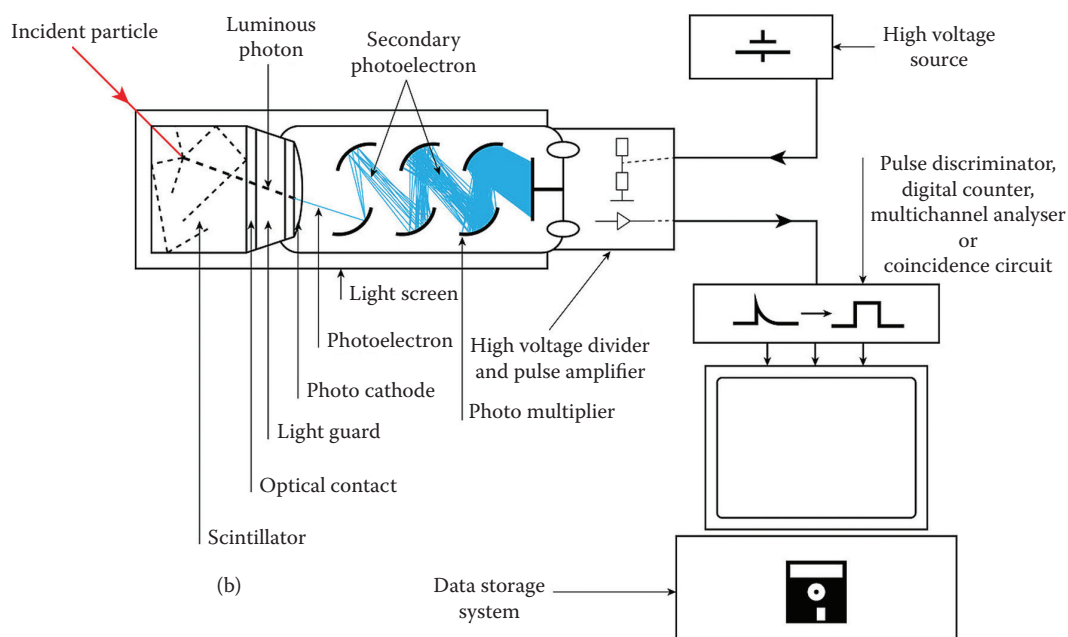


Figure O.40 (a) Principle of organic scintillator and (b) Photomultiplier tube.

Orifice

[fluid dynamics, thermodynamics] An opening, puncture, hole, exhaust, vent, void, or mouth, such as those found in a tube, PIPE, conduit, plate, or a body of material (organic or inorganic). An ORIFICE plate is a tool designed to measure FLOW rate, and can be used to reduce pressure or restrict flow.

Orifice, flow restrictions

[fluid dynamics] In any FLOW system, there is often the desire to control either the flow and pressure pertaining to that LIQUID. Pressure and flow are interdependent yet different. Controlling the flow or pressure can affect the other and the mechanism of control can lead to unexpected, inconsistent, or even “disastrous” results. Both pressure and flow control can be achieved, under the proper conditions, using a restriction in the plumbing line. Common tools are manual valves and fixed orifices of varying dimensions. Examples are found in kitchen and bathroom faucets, also known as “restrictive flow orifices.”

Ørsted, Hans Christian (Oersted) (1777–1851)

[energy, general, optics] A Danish scientist. Together with ANDRE-MARIE AMPÈRE (1775–1836) their groundbreaking work led to the revelation of the link between ELECTRICITY and MAGNETISM in 1819, resulting in an upsurge in the theoretical and experimental efforts in this field (see [Figure O.41](#)).



Figure O.41 Hans Christian Ørsted (1777–1851) (Oersted).

Orthogonal function

[atomic, computational] Functions that are perpendicular to each other, as considered a generalized version of vectors. The analysis of periodic functions with FOURIER ANALYSIS yields orthogonal functions. Two functions (ϕ) are orthogonal within a segment (a, b) if the dyadic expression yields: $\int_a^b \phi_m^* \phi_n dx = 0$, where ϕ_m^* is the complex conjugate. Examples of orthogonal functions are BESSEL FUNCTIONS, Chebyshev polynomials, Hermite polynomials, Legendre polynomials, sine and cosine, Spherical harmonics, Walsh functions, and Zernike polynomials, and generally EIGENFUNCTION with different eigenvalues are also orthogonal (e.g., Hamiltonian). One specific example of orthogonality applies to the Legendre polynomials, also referred to as “Legendre functions of the first kind,” or “zonal harmonics,” which are solutions to the LEGENDRE DIFFERENTIAL EQUATION. The Legendre polynomials are orthogonal over the segment $(-1, 1)$ as defined $\int_{-1}^1 \phi_m(x) \phi_n(x) dx = [2/(2n+1)]\delta_{mn}$, where δ_{mn} is the Kronecker delta.

Oscillating dipole

[general] Dipoles can be electronic, MAGNETIC, or mechanical (ACOUSTICS, FLUID DYNAMICS). A DIPOLE source consists of two monopole sources of equal strength but opposite PHASE (mechanical, acoustic) or opposite charge (atomic/molecular), separated by a small DISTANCE in relation to the wavelength of emission. Molecular dipoles are the most common and reveal information about material properties. Molecular dipoles were studied in great detail by PETER J. W. DEBYE (1884–1966), a chemist from the Netherlands. As a consequence, dipole moments are measured in “debye” units in his honor. Oscillating dipoles will produce some form of radiating ENERGY,

electromagnetic, and mechanical. An example of the electronic dipole is an analog ANTENNA. When the dipole is much shorter in length than the wavelength of the emitted radiation, the emitted POWER (P) at specific oscillation FREQUENCY ($\nu = \omega/2\pi$, ω the ANGULAR VELOCITY) as a function of the SOLID ANGLE (Ω) of the antenna can be defined as $dP/d\Omega = (\omega^4 P_0^2 / 32\pi^2 \epsilon_0 c^3) \sin \theta$, where P_0 is the power at the source, $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ is the permittivity of free space, and $c = 2.99792458 \times 10^8 \text{ m/s}$ is the speed of light.

Mechanical examples are an unboxed SPEAKER or a two-beater kitchen mixer in a highly viscous medium (e.g., dough), generates a dipole FLOW field, with an acoustic dipole as the oscillating representative model. On more simplified terms, the oscillating acoustic dipole generates a convolution of “BUBBLE flow.” Both pressure and velocity distributions have to be of the form of a SPHERICAL WAVE. The VELOCITY POTENTIAL (Φ_{bubble}) of a single oscillating bubble is described as $\Phi_{\text{bubble}} = (1/2)A(t)r^2(3\cos^2\theta - 1)$, where $A(t)$ is the periodic AMPLITUDE (generally expressed as pressure P or displacement), r is the radius to the source, and θ is the angle with the axis. The acoustic radiation field of a dipole (bipole), pair of two identical monopoles separated by a distance d (small with respect to the wavelength), can be represented as follows: $P(r) = P_0(e^{-i(kr_1 - \omega t)}/r_1) + P_0(e^{-i(kr_2 - \omega t)}/r_2) \equiv 2P_0(e^{-i(kr - \omega t)}/r)\cos(k\sin(\theta d/2))$, where P represents pressure, $k = 2\pi/\lambda$ is the wavenumber for wavelength λ , and t is the elapsed time (see Figure O.42).

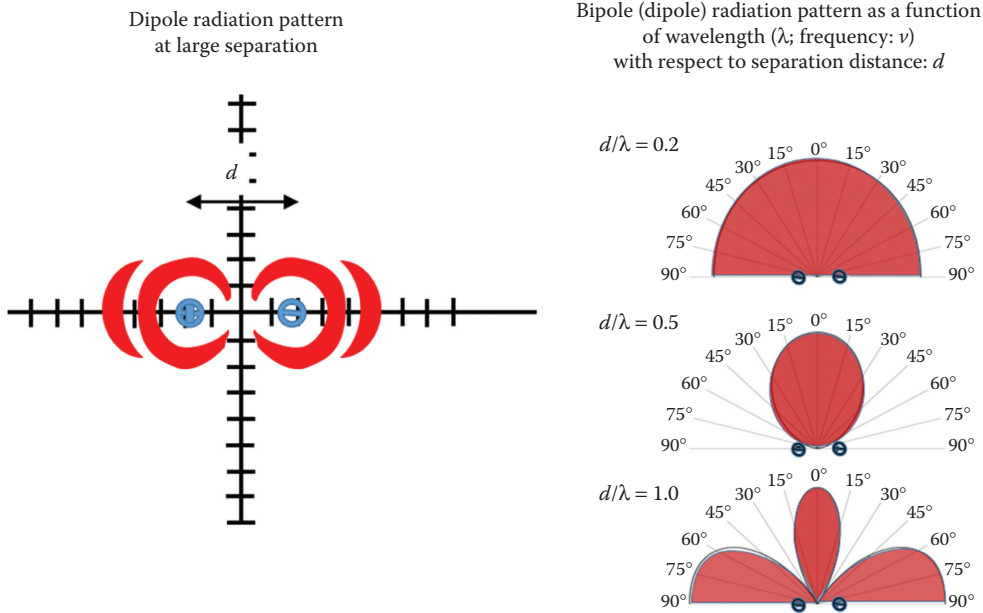


Figure O.42 Oscillating dipole.

Oscillating spring

[acoustics, electronic, fluid-dynamics, general] A MASS (m) attached to a spring that is extended by an external force (F_{ext}) will produce an OSCILLATION that can be damped (critically damped or, or under special conditions, may produce a non-damped HARMONIC OSCILLATION. The restoring force is produced by the extension and follows Hook's law: $\overline{F_{\text{spring}}} = -k\vec{x} = m(d^2/dt^2)\vec{x}$, where k is the spring constant and $\vec{x}$ is the

displacement. The solution to the nondamped oscillation as a function of time (t) provides a sinusoidal OSCILLATION described as $\vec{x}(t) = A \cos(\omega t + \phi)$, where A is the AMPLITUDE of the MOTION, the length of stretch of the spring, $\omega = \sqrt{k/m}$, and ϕ a PHASE factor. For the damped oscillation, the amplitude will decrease with time resulting from a “frictional force” ($F_{\text{friction}} = -b\vec{v}$, proportional to the velocity $\vec{v}$, with dampening factor b) described as $-k\vec{x} - b\vec{v} = -k\vec{x} - b(d\vec{x}/dt) = m(d^2/dt^2)\vec{x}$, with solution: $\vec{x}(t) = A_0 e^{-\lambda_{\text{damp}} t} \cos(\omega t + \phi)$, where $\lambda_{\text{damp}} = -(b \pm \sqrt{b^2 - 4mk}/2m)$; note there are two extreme situations next to the regular damped oscillation: overdamped $b^2 > 4mk$, and underdamped $b^2 < 4mk$. Generally, the square root will be positive with a real solution, whereas an underdamped situation may have an imaginary root solution. The DECAY time of the damped oscillation is $\tau_{\text{decay}} = 2m/b$. For the overdamped situation, the extended spring will return to the equilibrium position without oscillation, gradual exponential decay in extension only. In case a RESONANCE force is applied in a continuous fashion in a sinusoidal format, the oscillation will satisfy: $F_{\text{net}} = -k\vec{x} - b(d\vec{x}/dt) + F_0 \cos(\omega' t + \vartheta) = m(d^2/dt^2)\vec{x}$, which will oscillate at the driving frequency ω' and driving amplitude (see Figure O.43).

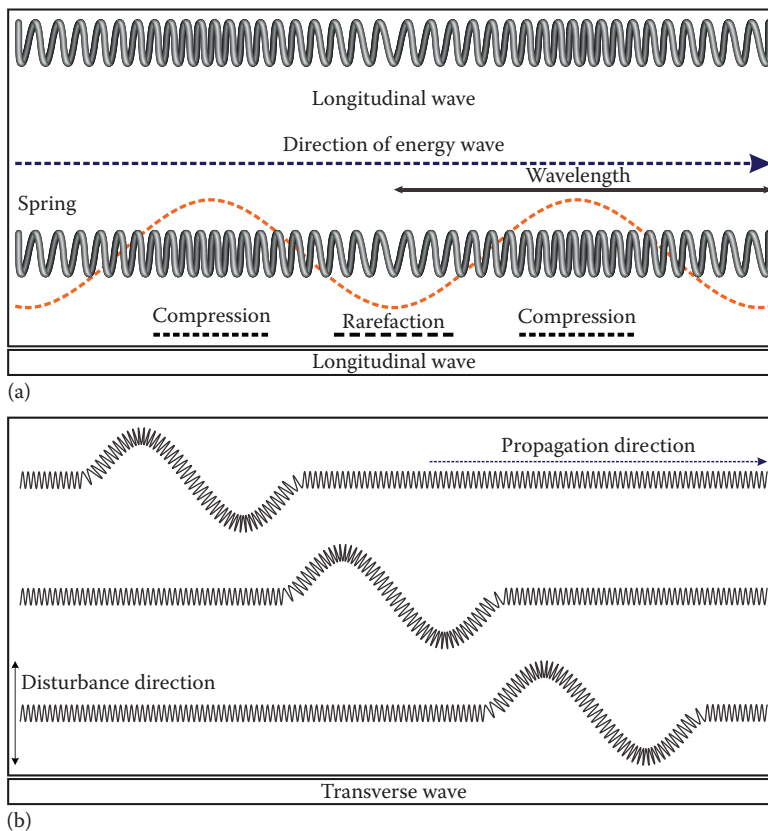


Figure O.43 (a) Oscillating spring. A spring can oscillate in transverse and longitudinal direction, the most common transverse spring oscillation is a vibrating string such as one found on a (b) guitar. (Continued)



(c)



(d)



(e)

Figure O.43 (Continued) (c–e) A trampoline is a complex spring, with stretch of material and suspension springs. Additional attractions are in bungee jumps.

Oscillation

[electromagnetism, general, mechanics] Periodic MOTION, repeatedly fluctuating above and below an arbitrary mean value. Examples are the pressure pattern in SOUND waves, electromagnetic signals as well as periodic solutions to mathematical equations (*also see* SIMPLE HARMONIC OSCILLATION). Oscillations can be driven by various sources and have external influences. A natural oscillation will require a start-up force and may remain in harmonic displacement (displacement distance: $s(t)$) as a function of TIME (t) indefinitely (i.e., free oscillation, without continuous driving force or undamped oscillation with continuous driving force); however, most oscillations require a continuous driving force or OSCILLATOR (e.g., FORCED OSCILLATION) or will eventually extinguish due to frictional or dampening forces (e.g., damped oscillation). A forced oscillation will result in RESONANCE as a function of time (t), under an external harmonic driving force ($F_{\text{ext}} = F_0 \sin(\omega_{\text{ext}} t)$), with ω_{ext} being the external oscillation angular frequency) to obey the WAVE EQUATION: $m(d^2x/dt^2) + b(dx/dt) + kx = F_0 \sin(\omega_{\text{ext}} t)$, where b is the dampening coefficient and k is the spring constant. Damped oscillation is the oscillation dampened by external frictional force (F_E)

with steady-state solution: $x = A \cos(\omega_{\text{ext}} t + \phi)$, where $A = (F_{e0}/m)/\sqrt{[(\omega_0^2 - \omega_{\text{ext}}^2)^2 + b^2(\omega_{\text{ext}}^2/m^2)]}$, and $\omega_0 = \sqrt{k/m}$. An example of a frictional force while the body with mass m in motion with displacement $s(t)$ is submerged in a LIQUID is defined proportional to the velocity (v) as $F_E = -b\vec{v} = -b[d\vec{s}(t)/dt]$, where b is the dampening constant and v is the velocity of motion, which yields NEWTON'S SECOND LAW as follows: $\sum F = ma = -ks - b[ds(t)/dt] = m[d^2s(t)/dt^2]$, where $a = [d^2s(t)/dt^2]$ is the acceleration experienced by the body in linear motion. Forced oscillation happens when a sinusoidal force is applied continuously and there will be three forces operating: a restoring SPRING FORCE, a frictional force, and an external oscillating driving force (F_E) with its own operating frequency (ω_E), yielding under Newton's second law: $\sum F = ma = -ks - b[ds(t)/dt] + F_E \sin(\omega_E t) = m[d^2s(t)/dt^2]$. Generally, an oscillation can reach a very high AMPLITUDE under resonance conditions, and in this case, the driving frequency matches the NATURAL FREQUENCY of the harmonic oscillator in one of the harmonic states, the resonant angular frequency: $\omega_R = \sqrt{\omega_0^2 - (b^2/2m^2)}$, which reduces to the NATURAL ANGULAR FREQUENCY ($\omega_0 = \sqrt{k/m}$) when the dampening is negligibly small (*also see* MASS-SPRING SYSTEM). In an electric system consisting of capacitors, inductors and resistors with a driving harmonic voltage source the equations are as follows. The sine-wave oscillator voltage source (V) is defined by both an INDUCTOR and a CAPACITOR with current (i) and inductance (L): $V = L(di/dt)$ and capacitance C , yielding $i = C(dV/dt)$. Combining both components gives $i + LC(d^2i/dt^2) = 0$, with undamped resonance ANGULAR-FREQUENCY $\omega = 1/\sqrt{LC}$ or frequency $\nu = 1/(2\pi\sqrt{LC})$ and solution $i = A \sin(\omega t + \phi)$, where ϕ is an undefined phase constant and A is a boundary condition dependent constant; this frequency has significant similarity to the PENDULUM frequency described by Galileo. When adding a dampener such as a RESISTOR (R) to the circuit, the differential equation becomes $i + RC(di/dt) + LC(d^2i/dt^2) = 0$, with an exponentially decaying solution: $i = Ae^{-(t/\tau)} \sin(\omega t + \phi)$, where τ is a factor indicating the DECAY time. Generally, the voltage output of the current driven oscillator is defined as $V_{\text{out}} = R_A i_{\text{in}}$, where R_A is the gain of the oscillator (technically a negative value with units of RESISTANCE [Ω]). In case the gain could be matched to a physical resistance, then the oscillator would be described by the undamped equation; however, there are many factors in the gain that cannot be matched by a linear resistance (e.g., phase shift and other nonlinear properties), which requires the introduction of a nonlinear amplifier that has a higher gain at low voltages and a low gain at a high voltage. This nonlinearity changes the format and the amplifier can, for instance, be CUBIC, which allows it to be described by the VAN DER POL EQUATION: $(d^2\xi/dt^2) + \epsilon(\xi^2 - 1)(d\xi/dt) + \kappa = 0$, where ξ is an electronic identity (current or potential) that varies with time t , whereas ϵ is a coefficient indicating dampening and attenuation in combination with COMPLIANCE, including system nonlinearities. Another form of oscillation is in RESONANCE. Mechanical resonance can be achieved by means of a PIEZOELECTRIC actuator. The piezoelectric oscillation has both mechanical and electrical influences, where the electric part can be represented by a Colpitts oscillator operating with frequency: $\nu = (2\pi\sqrt{L[C_1C_2/(C_1 + C_2)]})^{-1}$, where the inductor is represented by the piezoelectric crystal. (*also see* RESONANCE and PIEZOELECTRIC RESONANCE). An entirely different type of oscillation is in chemical binding where the chemical reaction changes periodically in time or location toward a higher entropy or a lower state of Gibbs free ENERGY. The increase in entropy is represented by an increase of product with an associated decrease in reactants through an intermediate reaction product. The rate of formation and destruction of intermediate dictates the chemical component oscillation process in both time and space. This process is referred to as OSCILLATORY REACTION (see Figure O.44).

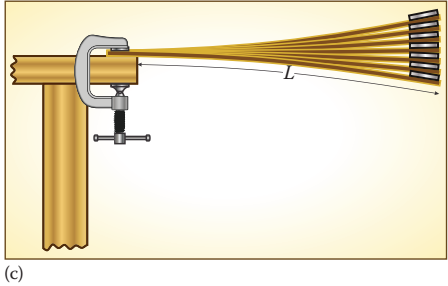
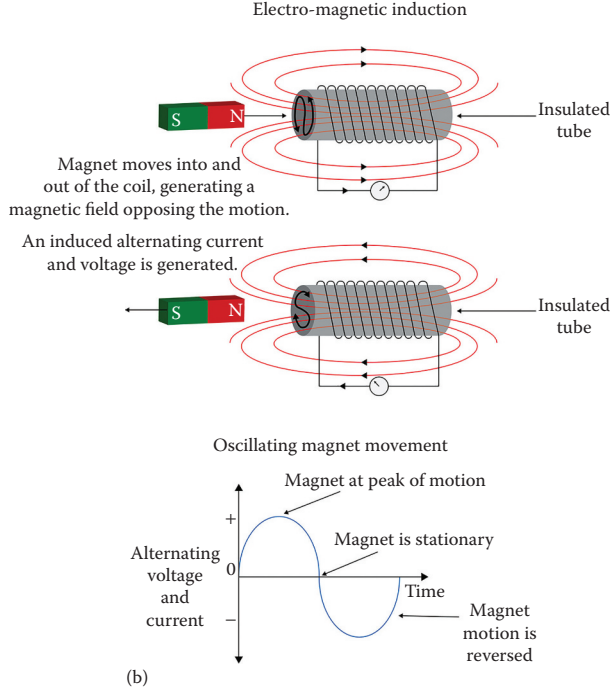
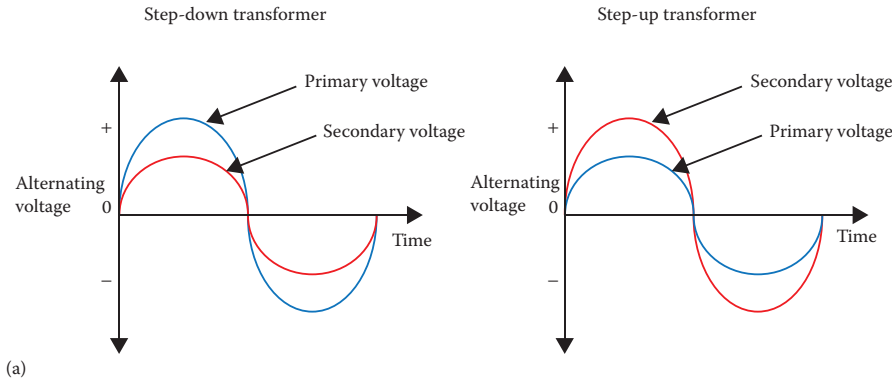
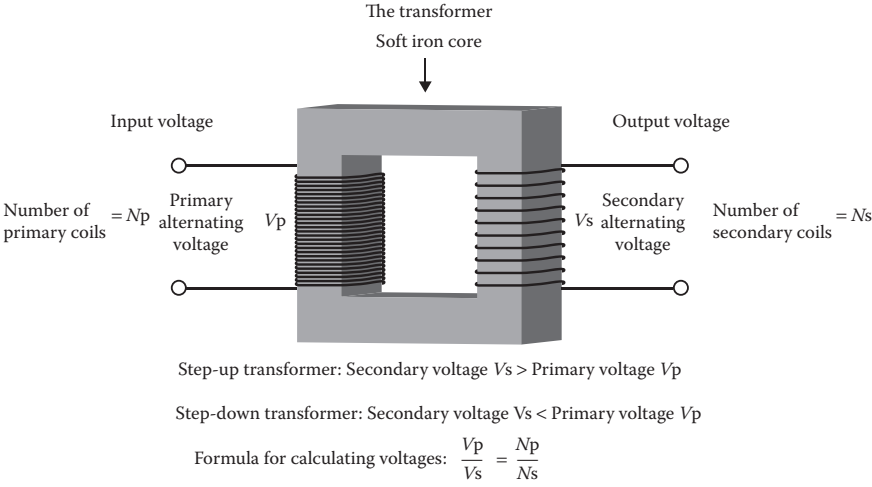


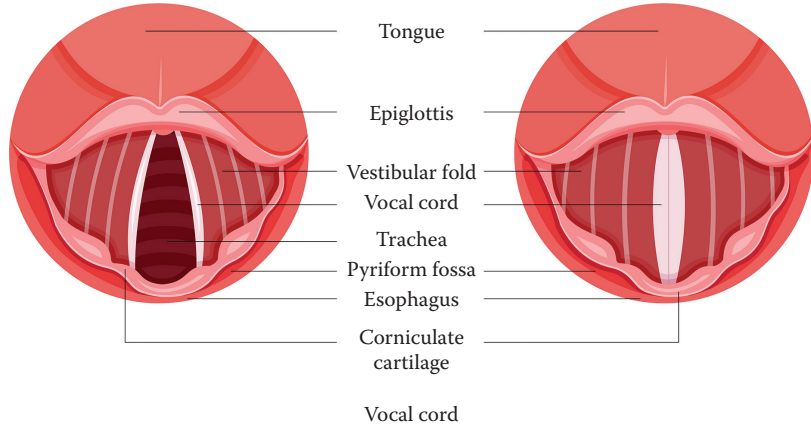
Figure O.44 (a,b) Generalized oscillation and (c) mass oscillating between elastic barriers.

Oscillator

[general] Mechanical or electronic mechanism of action resulting in a HARMONIC OSCILLATION of a specific medium including but not limited to electromagnetic (e.g., light and radio), electric (e.g., alternating current [AC] voltage), spring (e.g., tuning fork), molecular (i.e., temperature), and SOUND (e.g., vocal cords, drum, whistle, and woofer) (*also see* MASS–SPRING SYSTEM) (see [Figure O.45](#)).



(a)



(b)

Figure O.45 (a,b) Vocal cords oscillator.

Oscillator quantum number

[nuclear] In atomic PHYSICS, the particle MOTION becomes subject to the SCHRÖDINGER EQUATION due to fact that the QUANTUM harmonic oscillator is the quantum-mechanical equivalent to the classical harmonic oscillator. The application of an arbitrary electrical potential (i.e., COULOMB POTENTIAL) considered in the vicinity of a stable equilibrium point can generally be approximated as a harmonic potential. The quantum harmonic oscillator is one of the most significant mathematical systems in QUANTUM MECHANICS. The quantum harmonic oscillator can be described by the Hamiltonian of the oscillating PARTICLE (e.g., electron) with mass m as $H_{\text{opp}} = (p_{\text{opp}}^2/2m) + (1/2)m\omega^2 x_{\text{opp}}^2$, where $p_{\text{opp}} = i\hbar(\partial/\partial x)$ is the momentum operator, $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is the Planck's constant, $\omega = 2\pi\nu$ is the ANGULAR VELOCITY, ν is the frequency of motion, and x_{opp} is the position operator. The Schrödinger equation now becomes $H_{\text{opp}}\Psi = E\Psi$ (this corresponds to $-(\hbar^2/2m)(d^2/dx^2)\Psi(x) + U(x)\Psi(x) = E\Psi(x)$, where $U(x)$ is the potential ENERGY EIGENFUNCTION, which can be represented for the quantum harmonic oscillator as $U(x) = (1/2)k_{\text{spring}}x^2$), with eigenvalues solutions $|\Psi$ for the WAVEFUNCTION at the energy states E , under boundary conditions described by de Broglie relationship. The SOLUTION series are $\Psi_n(x) = (1/\sqrt{2^n n!})(m\omega/\pi\hbar)^{1/4} e^{-(m\omega x^2/2\hbar)} H_n(\sqrt{(m\omega/\hbar)}x)$, where $n = 0, 1, \dots$ is the oscillatory quantum number with corresponding eigenvalues for the energy levels $E_n = \hbar\omega[n + (1/2)] = [n + (1/2)]\hbar\nu$ and $H_n = (-1)^n e^{x^2} (d^n/dx^n)(e^{-x^2})$, which are Hermite polynomials.

Oscillatory flow

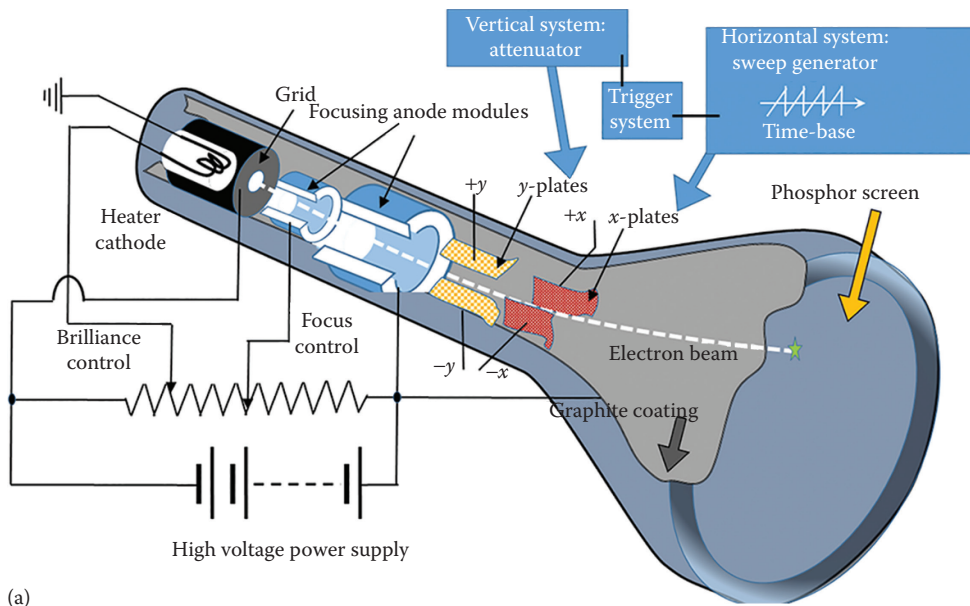
[biomedical, fluid dynamics] Biological flow can be oscillatory or pulsatile, as can be system flow (e.g., piston flow or the FLOW from a water pump in an automobile). In biological systems, the RESPIRATION, vascular, and auditory flow is oscillatory pulsatile. Oscillatory flow has, for instance, the Womersley ($\alpha_{wo} = r\sqrt{\rho\omega/\eta}$, where r is the radius of the conduit, ω is the angular velocity FREQUENCY (ν) of the OSCILLATION ($\omega = 2\pi\nu$), ρ is the fluid density, and η is the VISCOSITY and Strouhal ($Sr = \nu L/v$, where v is the frequency of VORTEX SHEDDING, L is the characteristic length, and v is the velocity of flow) number as boundary conditions. Small Strouhal number will represent LAMINAR FLOW. The PULSATILE FLOW obeys the Navier–Stokes equation, and has WAVE pattern characteristics. Because of INERTIA as well as viscosity and strain, the wave movement for a FLUID in oscillatory flow will be out-of-phase over the radial velocity distribution at any location along the length of flow (see BLOOD FLOW).

Oscillatory reaction

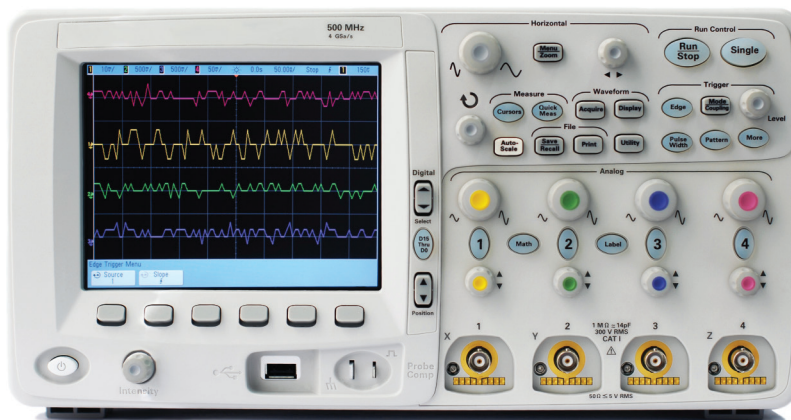
[chemical, energy, quantum] A chemical binding reaction where the chemical reaction changes periodically in time or location toward a higher entropy or a lower state of Gibbs free ENERGY. The increase in entropy is represented by an increase of product with an associated decrease in reactants through an intermediate reaction product. The rate of formation and destruction of intermediate dictates the chemical component OSCILLATION process in both time and space. One example is the Belousov–Zhabotinsky reaction, a competing effort between two reagents: bromide (Br) and cerium (Ce). The process involves the reactive oxidation of an organic substrate by the highly reactive bromate ion (BrO_3^-), in the presence of bromide ions (Br^-) and the reaction is catalyzed by a metal ION such as the constituent ion of cerium (Ce^{3+}), which has two potential states of oxidation. The bromide ion is oxidized by bromate until the concentration drops below a threshold value when the process is replaced by the OXIDATION of the cerium ion, both reactions represented as follows: $\text{BrO}_3^- + 2\text{Br}^- + 3\text{H}^+ \rightarrow 3\text{HOBr}$ (slow) and $\text{BrO}_3^- + 4\text{Ce}^{3+} + 5\text{H}^+ \rightarrow \text{HOBr} + 4\text{Ce}^{4+} + 2\text{H}_2\text{O}$ (fast). The cerium ion reduction is in fact inhibited by the presence of the bromide ion creating the environment for a cyclic reaction. In this cyclic reaction, the bromide will be reduced in quantity until the Cesium reaction takes over again. Both the products of the bromate reaction forming a bromide hydroxyl (HOBr) as hypobromous ACID and the cesium reaction will now interact intermittently with the organic MATTER, which in turn creates the bromide ion needed to shut down the Cesium reaction in the format: $\text{Organic Matter} + \text{Ce}^{4+} + \text{HOBr} \rightarrow \text{Br}^- + \text{Ce}^{3+} + \text{Bromated Organic Matter} + \text{Oxidized Organic Matter}$, which in turn will refuel the Bromide reaction. This oscillatory reaction process may also create an anolyte migratory WAVE pattern (i.e., periodic mass-transport). Additionally, the exothermic portion of the described reactions will in turn also describe a temporal and spatial oscillatory process, called a THERMOKINETIC OSCILLATOR. Metabolic processes such as the formation of ATP and concurrent depletion of ADP are spatially confined by the MEMBRANE processes, imposing spatial constraints on the reaction process, which in turn leads to oscillatory reaction processes in time as well as space.

Oscilloscope

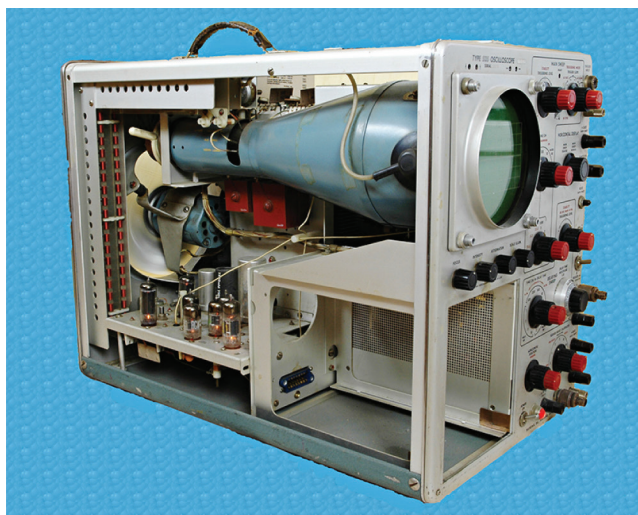
[general] Device used to display time-varying signals by diverting an electron beam (CATHODE ray) in the vertical direction based on the MAGNITUDE of the SIGNAL strength, while the horizontal axis is a time frame reference. The oscilloscope uses a VACUUM tube with a cathode-based electron gun and horizontal and vertical deflection plates that are electrically charged by external potentials. The electron beam is targeting a fluorescent screen that writes the time-dependent AMPLITUDE for visual interpretation (see Figure O.46).



(a)



(b)



(c)

Figure O.46 (a–c) Oscilloscope.

Osmolality

[biomedical, chemical] Measure of the moles or osmoles (molar concentration of individual SOLUTE particles) of constituent solute per kilogram of SOLVENT medium expressed as (mol/kg, or molal). Note this compares to osmolarity by conversion of kilograms to liters.

Osmolarity ($\Sigma[C_i]$)

[biomedical, chemical] Sum of the molar concentrations ($[C_i]$) of dissolved solutes (measure of osmoles of solute per liter of SOLVENT medium), considering the partial pressures of the individual constituents: $\Sigma[C_i]$. When the solute concentration exceeds the EQUILIBRIUM STATE or the concentration assessed at the starting point, the FLUID becomes hyperosmotic. When the loss of electrolytes exceeds the loss of solvent, the SOLUTION becomes hypoosmotic. When the situation at the beginning and end are equal in osmotic value, although the absolute quantity need not be preserved, the solution is isosmotic or ISOTONIC. This also applies to two solutions in equilibrium across a SEMIPERMEABLE MEMBRANE. Ionic compounds, such as salts, in solution will generally dissociate into their constituent ions, thus giving the osmolarity of the two dissolved constituent. In contrast, the molarity of the solution is based on the base compound, the joint components of the dissociated solute.

Osmole

[biomedical, chemical] Molar concentration of individual SOLUTE particles.

Osmosis

[biomedical, chemical, thermodynamics] “Active” transfer of SOLVENT through a MEMBRANE (most notably SEMIPERMEABLE MEMBRANE) based on a difference in concentration of a variety of solutes. The FLUID transfer (FLOW and FLUX) for osmosis is generally faster than regular DIFFUSION. Specifically in biological

applications, the osmotic transfer of interstitial fluid across the CELL MEMBRANE relies on gates that will open, or open wider under the influence of a CHEMICAL GRADIENT across the BARRIER (see Figure O.47).

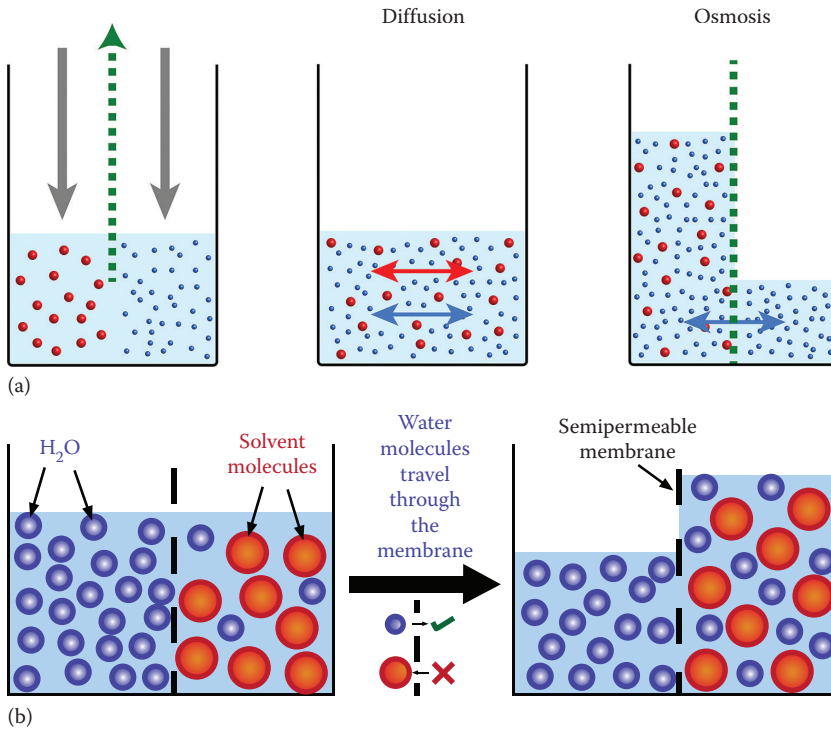


Figure O.47 (a,b) Osmosis.

Osmotic coefficient (Φ_{osm})

[biomedical, fluid dynamics] Quantity that provides a characterization of the deviation from ideal behavior for a SOLVENT, as defined by **RAOULT'S LAW**, defined with respect to **OSMOLALITY** as $\Phi_{\text{osm}} = (\mu_A^* - \mu_A) / (RTM_A \Sigma[C_i])$, where μ_A is the chemical potential of the solvent in the SOLUTION, μ_A^* is the chemical potential of the solvent, M_A is the **MOLAR MASS**, $R = 8.3144621(75) \text{ J/Kmol}$ is the **GAS constant**, $\Sigma[C_i]$ is the **osmolarity**, and T is the temperature (in Kelvin). The osmotic coefficient (based on molality) is related to the **Gibbs free ENERGY** ($G(T, V, N)$), in this case available in excess to a stationary (ideal solvent) condition, as $RT(1 - \Phi_{\text{osm}}) = G_{\text{excess}} - \Sigma[C_i](dG_{\text{excess}}/d[C_i])$.

Osmotic pressure

[thermodynamics] Solute pressure that is a direct function of the **OSMOLALITY** ($\Sigma[C_i]$) of a solution: $\Pi = \Sigma[C_i]RT$, where T is the **TEMPERATURE** and $R = 8.3144621(75) \text{ J/Kmol}$ the **GAS constant**.

The net osmotic pressure across a SEMIPERMEABLE MEMBRANE will directly depend on the net cumulative concentration difference across the MEMBRANE (see [Figure O.48](#)).

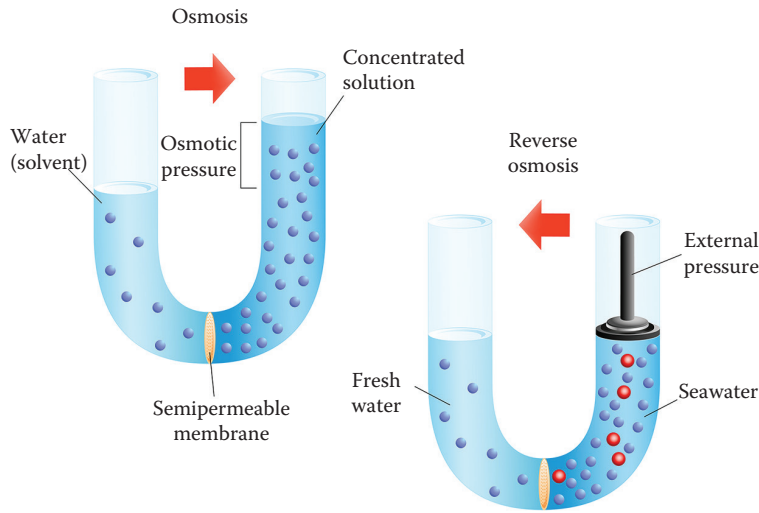


Figure O.48 Osmotic pressure.

Osmotic pressure (Π_{osm}), Van't Hoff relation for

[fluid dynamics, thermodynamics] Chemical pressure associated with the concentration of a SOLUTE in a SOLVENT, with respect to the individual solutes, each providing a partial pressure that resembles the partial pressure for a GAS. The osmotic pressure (Π_{osm}) is a function of the number of ions that result from the dissociation of the solute (i), the concentration of the SOLUTE ($[\text{Solute}]$), and the OSMOTIC COEFFICIENT (ϕ_{osm}) indicating the mobility of the solute: $\Pi_{\text{osm}} = i\phi_{\text{osm}}[\text{Solute}]RT$, where T is the ABSOLUTE TEMPERATURE and $R = 8.3144621(75) \text{ J/Kmol}$ is the universal gas constant. Osmotic pressure influences the boiling point of a LIQUID as well as the FREEZING point. The osmotic pressure of a SOLUTION can be derived from the freezing point depression (ΔT_f) based on $i\phi_{\text{osm}}[\text{Solute}] = \Delta T_f / 1.86$. When two solutions are separated by a SEMIPERMEABLE MEMBRANE, the balance can be iso-osmotic for identical osmotic pressure and hence no DIFFUSION, or alternatively higher on side 1 (arbitrary, generally outside, vs. inside [2]): hyperosmotic, or reduced pressure on the outside: hypoosmotic.

Ossicles

[biomedical] The three critical mechanical components in the human MIDDLE EAR responsible for the HEARING process, connecting the tympanic MEMBRANE to the oval membrane on the cochlea by means of the hammer (malleus), anvil (incus), and stirrup (stapes) (see [Figure O.49](#)).

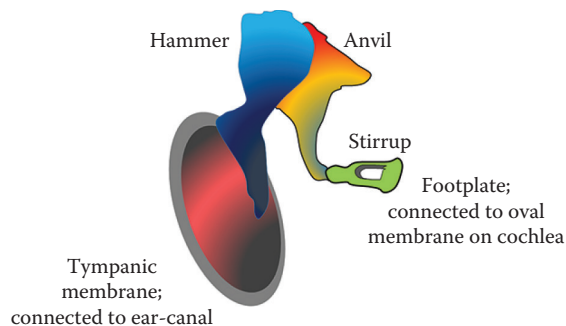


Figure O.49 The ossicles of the middle ear.

Osteoblast

[biomedical, mechanics] Large cell in bone responsible for the synthesis and mineralization of bone formation. The function of the OSTEOLAST persist from initial bone formation to bone remodeling in regenerative processes. Osteoblasts are part of a closely packed sheet of cells close to the external surface of the bone. Osteoblasts are “activated” by mechanical strain. The osteoblast will attempt to reinforce the bone where the strain may have the highest risk for crack formation (i.e. mechanical healing action) (see [Figure O.50](#)).

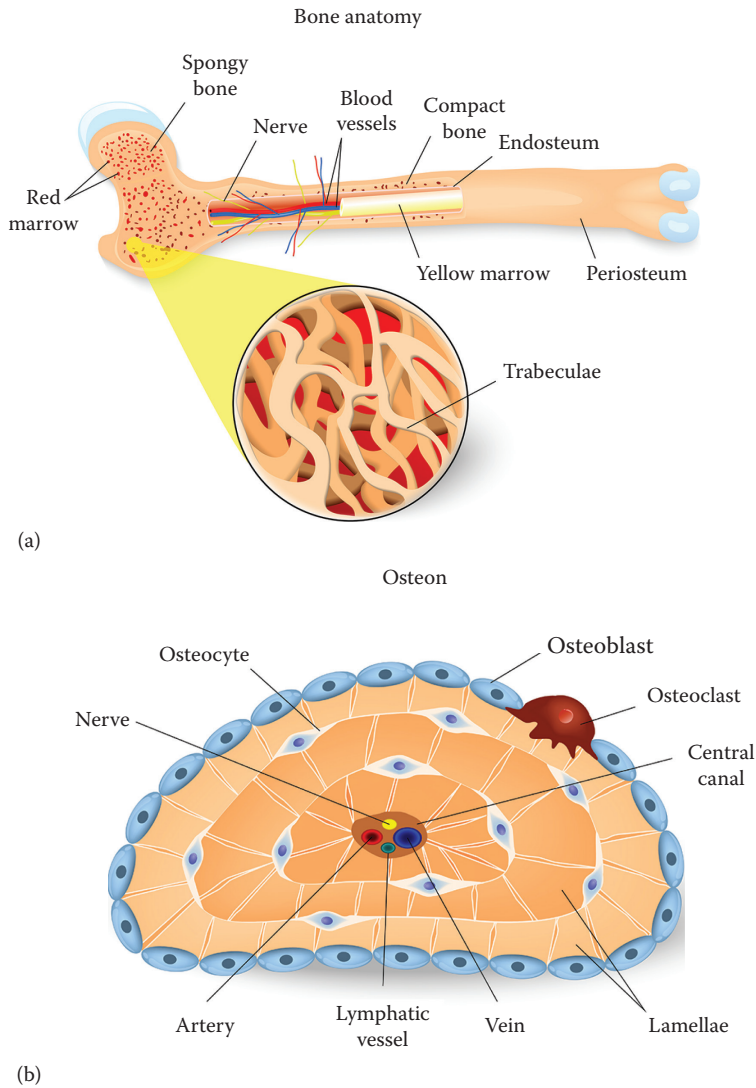


Figure O.50 (a) Osteoblast in osteon of (b) bone formation.

Osteoclast

[biomedical] Large cell in bone that is responsible for the resorption of bone cells that are nearing the end of their useful life span as part of the continuous regeneration process. Osteoclasts are spread throughout the bone. An osteoclast performs a function in bone remodeling in response to applied strain Osteoclasts are descended from stem cells (see [Figure O.51](#)).

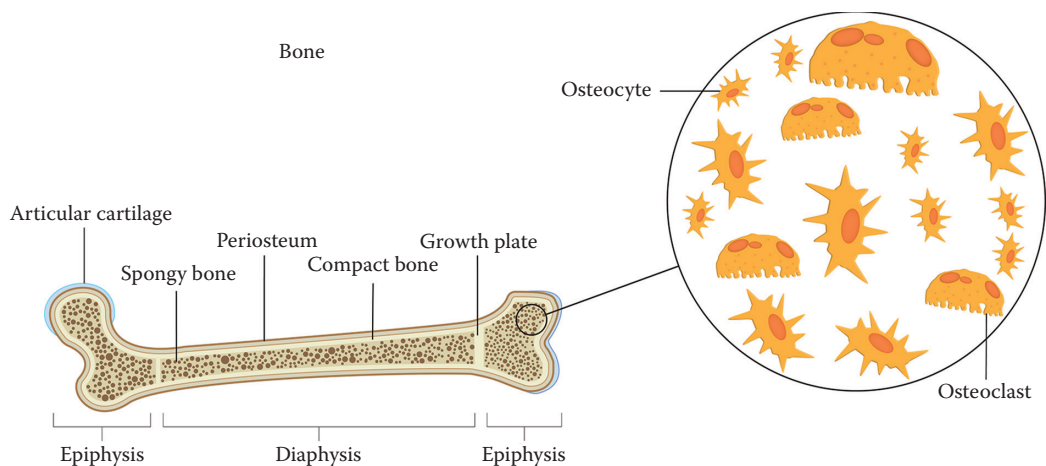


Figure O.51 Osteoclast.

Ostwald, Dilution law

[atomic, general, quantum] See **DILUTION LAW OF OSTWALD**.

Ostwald, Wilhelm (1853–1932)

[chemical, solid-state, quantum] A chemist from Germany whose work contributed to the ion-theory published by SVANTE AUGUST ARRHENIUS (1859–1927) (see [Figure O.52](#)).



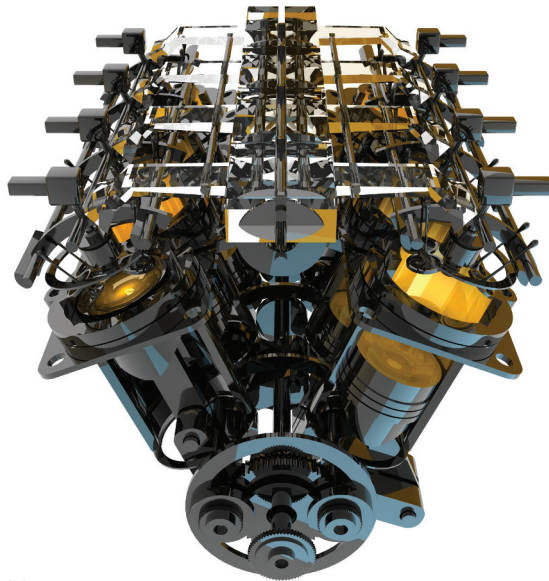
Figure O.52 Wilhelm Ostwald (1853–1932).

Otto, Nikolaus August (1832–1891)

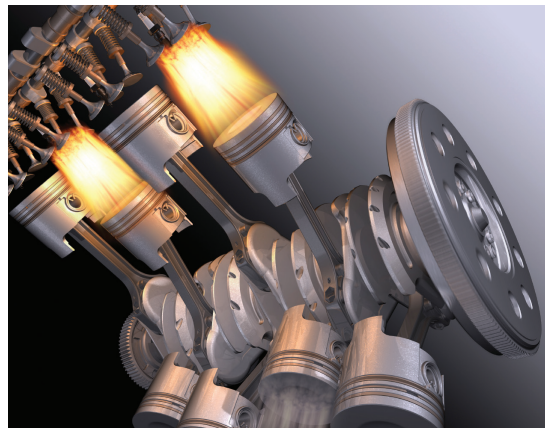
[mechanics, thermodynamics] An engineer from Germany, or the Prussian Empire at the time. He is the inventor of the first INTERNAL-COMBUSTION ENGINE using the four-stroke mechanism of intake through the intake VALVE (increasing volume), compression, combustion with the use of a spark-plug—followed by EXPANSION and forced movement of the piston, and the final stroke pushing the exhaust fumes out through the exit valve) with the use of a piston transferring the ENERGY into work (see [Figure O.53](#)).



(a)



(b)



(c)

Figure O.53 (a) Nikolaus August Otto (1832–1891) and (b,c) Otto internal combustion principle for a V-8 engine.

Otto cycle

[thermodynamics] Idealized thermodynamic cycle representing the mechanism of action of a four-stroke INTERNAL COMBUSTION ENGINE, operating by means of spark ignition, as found in a reciprocating piston engine. The importance of the Otto cycle is the prevalence of this thermodynamic cycle in automobile engines. The process is named after NIKOLAUS AUGUST OTTO (1832–1891), who described the operations of the four-stroke engine in 1876. The efficiency of an ideal Otto cycle is described by the ratio of work performed to the heat input: $\eta_{\text{eff}} = (\text{work}/\text{heat input}) = (Q_H + Q_L)/Q_H = 1 + (1/r_{\text{comp}}^{\gamma_{\text{PV}} - 1})$, where Q_L is the loss of heat due to the exhaust of warm fluid, Q_H is the combustion heat, $r_{\text{comp}} = V_1/V_2$ is the compression ratio comparing the cylinder volume at the end of intake (V_1) to the volume under compression (reached primarily just after combustion; combustion in modern engines is several degrees before the top position of the cylinder), and the coefficient γ_{PV} represents the adiabatic process in the PV diagram: $T_4V_1^{\gamma_{\text{PV}} - 1} = T_3V_2^{\gamma_{\text{PV}} - 1}$ and $T_1V_1^{\gamma_{\text{PV}} - 1} = T_2V_2^{\gamma_{\text{PV}} - 1}$ (see Figure O.54).

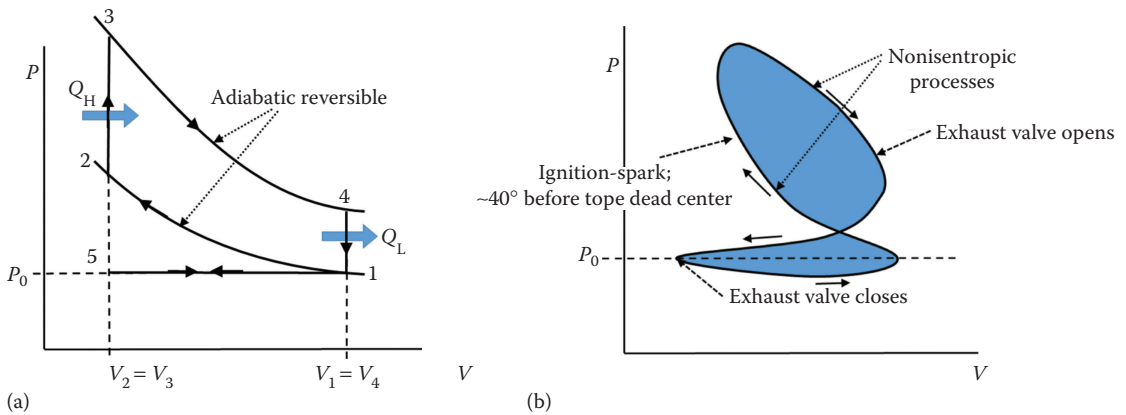


Figure O.54 Otto cycle: (a) ideal and (b) actual.

Outer ear

[general] The EAR canal extending to the open AIR along with the external ear shell, connecting with the MIDDLE EAR at the tympanic MEMBRANE, further transferring the mechanical (acoustic) ENERGY by means of the OSSICLES to the INNER EAR (see [Figure O.55](#)).

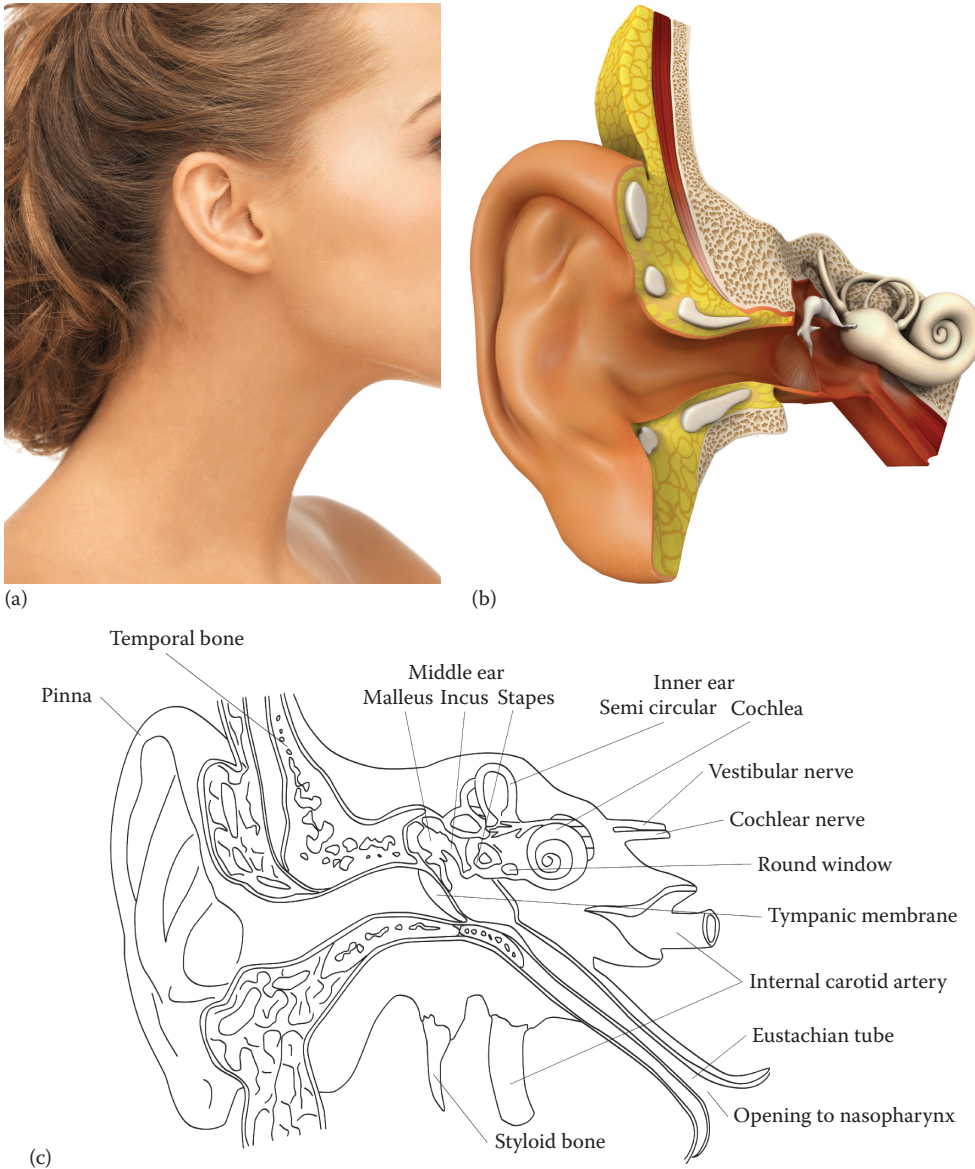


Figure O.55 (a,b) Outer ear anatomy and (c) reference to middle and inner ear.

(Continued)

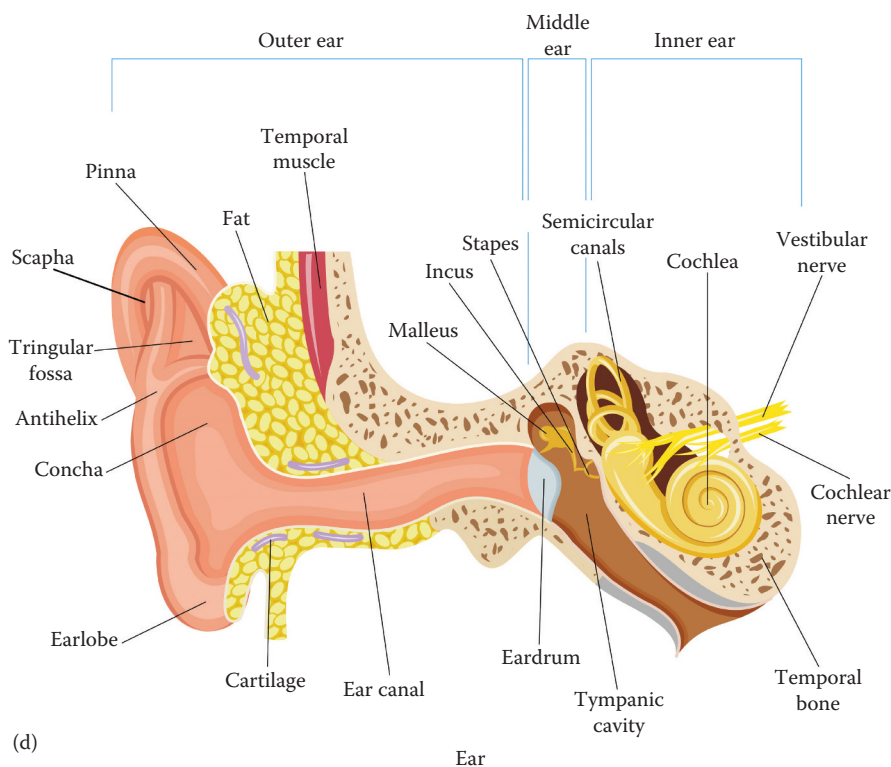


Figure O.55 (Continued) (d) reference to middle and inner ear.

Overtone

[acoustics, general] Waves emitted in addition to the FUNDAMENTAL FREQUENCY; the first overtone equates to the second harmonic (*see* HARMONICS).

Oxidation

[biomedical, chemical] EXOTHERMIC REACTION that combines (oxidation) oxygen with respect to another CHEMICAL COMPOUND. The process of oxygen removal is generally endothermic and is referred to as “reduction.” Oxidation of carbohydrates and fossil fuels will generally result in the formation of water and carbon dioxide under the oxidation and combustion processes. A chemical reaction that involves changing the oxygen binding (oxidation) process is referred to as a “REDOX REACTION.” More generally, a redox reaction pertains to the electron transfer between species. For example, combining oxygen and hydrogen forming water pertains to the fact that oxygen is reduced and hydrogen is oxidized. Another example of an oxidation reaction is the combining of hydrogen and fluorine: $H_2 + F_2 \rightarrow 2HF$.

Oximeter

[biomedical, optics] *See* PULSE OXIMETER.

Oxygen [^{16}O , O_2]

[biomedical, chemical, general] Chemical ELEMENT that is used in conversion of chemical elements to form ENERGY. The Earth's ATMOSPHERE consists of approximately 20.95% oxygen at sea level, less at greater altitudes. Oxygen in the UNIVERSE as we currently know is presumably the third most prevalent chemical, after hydrogen and helium. In biological units, oxygen forms a significant component of the following chemical compounds: carbohydrates, fats, nucleic acids, and proteins. In inorganic media, oxygen is part of the following chemical

structures: silicon dioxide (silica, found most prominently as quartz), water, and many oxides. Note that most METAL oxides are transparent, whereas under environmental conditions generally a hydroxide is formed, including both hydrogen and oxygen. Oxygen was discovered around 1773 by Swedish chemist CARL WILHELM SCHEELLE (1742–1786), and independently by English theologian and chemist JOSEPH PRIESTLEY (1733–1804) in 1774, and potentially by French chemist ANTOINE-LAURENT DE LAVOISIER (1743–1794) in 1778, who ultimately named it. Oxygen liquefies at 90.20 K and turns solid at 54.36 K (see Figure O.56).

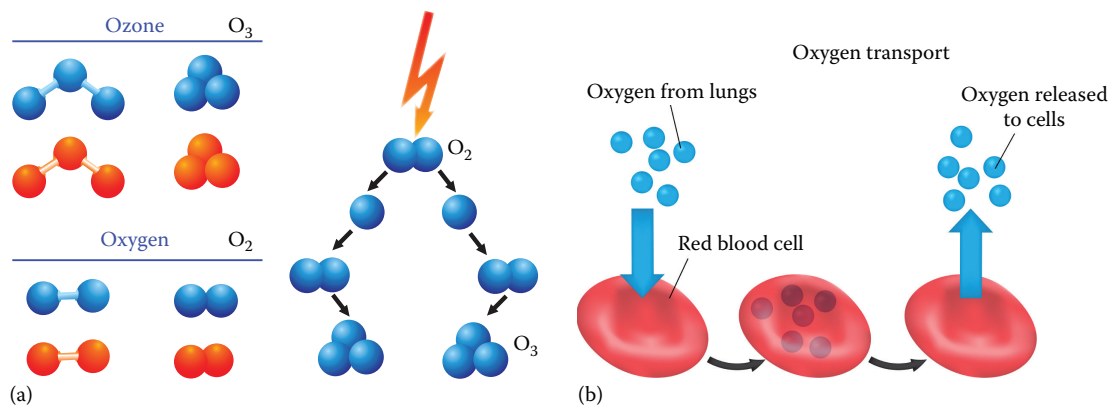


Figure O.56 (a) Oxygen and its relation to ozone and (b) biological oxygen transportation through uptake by hemoglobin in the lung and release in tissue partially regulated by osmotic pressure.

Oxygen sensor

[biomedical, chemical] A sensor that measures the quantity of oxygen as either relative or absolute. Oxygen sensors are used to measure the reaction process of chemical events. A specific application is found in automobiles to regulate the fuel-oxygen mixture for high efficiency combustion, also referred to as “Lambda sensor.”

Ozone, [O_3]

[biomedical, chemical, general] Inorganic molecule with scientific name: $1\lambda^1, 3\lambda^1$ – trioxidane, also named μ – oxidodioxygen. Unstable allotrope of the ELEMENT oxygen, compared to the diatomic allotrope O_2 , discovered in 1865 by Swiss chemist JACQUES-LOUIS SORET (1827–1890). Condensation point is 161 K and MELTING POINT is 80 K (see Figure O.57).

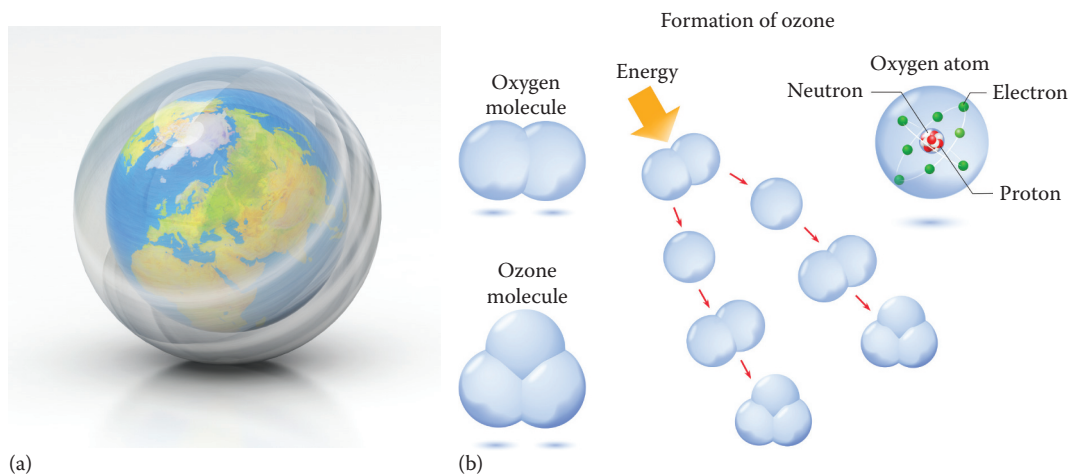


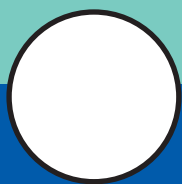
Figure O.57 (a) Ozone gas (NPT, normal pressure and normal temperature) and (b) formation process.



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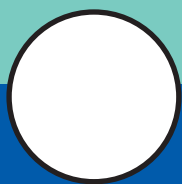
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Preface

The purpose of this *encyclopedia* is to provide a single, concise reference that contains terms and expressions used in the study, practice, and applications of physical sciences. The reader will be able to quickly identify critical information about professional jargon, important people, and events. This encyclopedia gives self-contained definitions with essentials regarding the technical terms and their usages and information about important people in the following areas of physics:

- Acoustics
- Astronomy/astrophysics
- Atomic physics
- Biomedical physics
- Chemical physics
- Computational physics
- Condensed matter
- Dynamics
- Electromagnetism
- Electronics
- Energy
- Engineering
- Fluid dynamics
- General
- Geophysics
- High-energy physics
- Imaging
- Instrumentation
- Materials sciences
- Mechanics
- Meteorology
- Nanotechnology
- Nuclear physics
- Optics
- Quantum physics
- Relativistic physics
- Rheology
- Sensing
- Signal processing
- Solid-state physics
- Theoretical physics
- Thermodynamics
- Ultrafast phenomena

This reference differs from the standard dictionaries in its inclusion of numerous illustrations, including photographs, micrographs, diagrams, graphs, and tables, which support the textual definitions and draw the reader into the explanation to enhance didactic value. Together, these over 2500 entries will educate the reader about the current practice of physics and its applications in biomedicine, materials sciences, chemical engineering, electrical engineering, mechanical engineering, geology, astronomy, meteorology, and energy.

It is envisioned that novices and trainees, in addition to seasoned professionals, will find this resource useful, both for sustained reading and for taking a dip into the topics periodically. The contents are also designed to help the professionals who are new to a work environment and recently enrolled students who need to become more familiar with terminology and nuances relevant to certain research and applications. Moreover, it will assist in understanding the primary literature as well as technical reports and proposals. Finally, any student from the high school to graduate levels should be able to benefit from the broad and applied emphasis of this concise encyclopedia, which may support undergraduate courses in applied sciences for nonscience majors.

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P

***p* (linear momentum)**

[general, mechanics] $p = mv$, where m is the mass of the object in MOTION with velocity v (see MOMENTUM).

Pacemaker

[biomedical] Biological or electronic unit providing the excitation mechanism that induces a self-sustained DEPOLARIZATION process in the HEART muscle. The biological unit in mammals is located in the atrium and consists of a small group of cells with a range of natural depolarization periods, presumably based on a cellular ionic leak that eventually generates a full cellular depolarization, generating an impulse that is transmitted to neighboring MUSCLE cells that will respond to the threshold exceeding voltage spike. Various cells have specific depolarization rates, thus allowing for a regulation mechanism of the heart rate. The depolarization rate can be influenced externally in limited amount by the autonomic nerve system and by hormonal influences. The artificial pacemaker is an electronic device that generates an electrical pulse that is conducted to the heart muscle by means of electrodes and is powered by a BATTERY. Artificial pacemakers have evolved of time from fixed rate to on demand. Additionally, bioelectricity is being investigated to power modern pacemakers, eliminating the need for surgical battery replacement. The on-demand pacemaker “measures” ACTIVITY and regulates the emission rate of the current spikes to longer or shorter intervals. The pacemaker’s purpose is the general BLOOD supply to the body and brain as well as mitigation of external influences to maintain HOMEOSTASIS and accommodate the efficiency of the organs with respect

to their particular functions. Artificial pacemakers are a major economic force in medical device design (see [Figure P.1](#)).

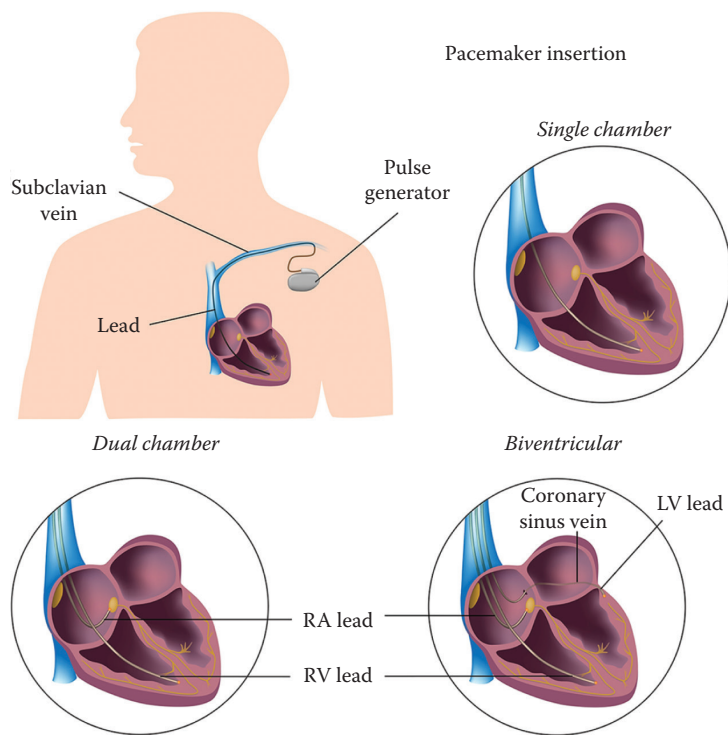


Figure P.1 Image of artificial pacemaker.

Packing fraction

[nuclear] The difference between the ATOMIC WEIGHT in nuclear mass units (standard atomic weight: M_a) and the mass number of an ELEMENT (A), divided by the mass number, multiplied by 10,000. Packing fraction = $\left[(M_a - A) / A \right] \times 10,000$. Packing fraction is used as an indicator of nuclear stability.

Pair annihilation

[atomic, nuclear] See ANNIHILATION.

Pair formation

[nuclear] The formation of an elementary PARTICLE and its antiparticle. The creation process involves the application of a trigger phenomenon (generally a BOSON; e.g., PHOTON) with high enough ENERGY to accommodate the formation of two particles that balance the energy in REST MASS and movement (i.e., kinetic energy content). Since the CONSERVATION LAWS apply, the two particles shall respectively have the inverse properties. The passage of gamma rays with energy greater than or equal to 1.022 MeV in the proximity of the atomic NUCLEUS of certain ELEMENTS will generate an electron and a positron pair. This process was first described by PAUL ADRIEN MAURICE DIRAC (1902–1984) in 1928 basing his premonitions on relativistic wave-mechanics theory, and was subsequently observed by CARL DAVID ANDERSON (1905–1991) in 1932. In the atomic annihilation process, under the influence of positron RADIATION two gamma photons with 511 keV are produced that are emitted in perfect opposite directions ($\pm 5^\circ$). POSITRON EMISSION TOMOGRAPHY uses this principle for imaging purposes. Another kind of pair formation is found in support of SUPERCONDUCTIVITY

called a “COOPER PAIR,” consisting of two electrons (*see* COPPER PAIR and POSITRON EMISSION TOMOGRAPHY) (*see* Figure P.2).

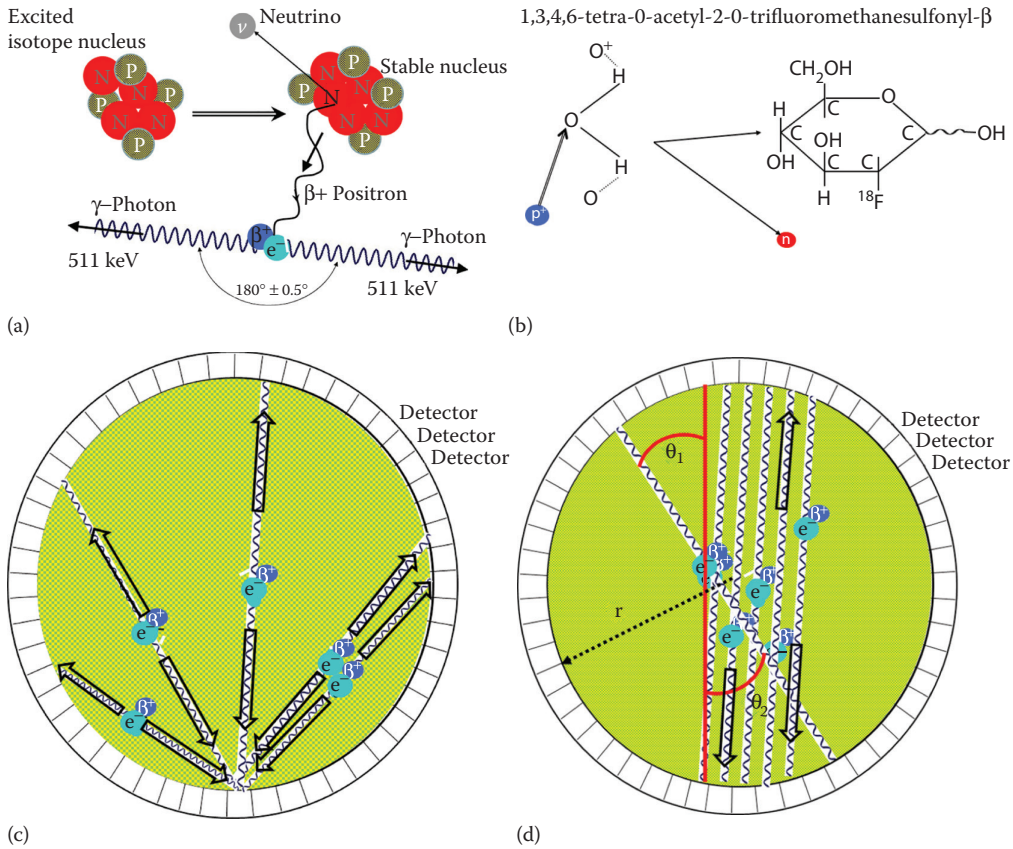


Figure P.2 (a–d) Process of photon pair formation in positron emission tomography.

Pairing energy (P_{pair})

[atomic, nuclear] In the event of the pairing of electrons, the SPIN pairing ENERGY refers to the energy required to accommodate two paired electrons to share one orbital and what the effects are on the molecules surrounding this orbit. The electron–electron interactions must be taken into account, which involves Hund’s rule and PAULI EXCLUSION PRINCIPLES. For instance, Hund’s rule predicts for $d^1 - d^3$ systems that the electrons will not pair and occupy the t_{2g} -set spin configuration. The electron configuration will largely depend on the difference between the pairing energy (P_{pair}) and the electron gap energy (Δ_0), providing a higher spin configuration energy when the pairing energy exceeds the electron band-gap. The pairing energy is expressed in cm^{-1} .

Paleomagnetism

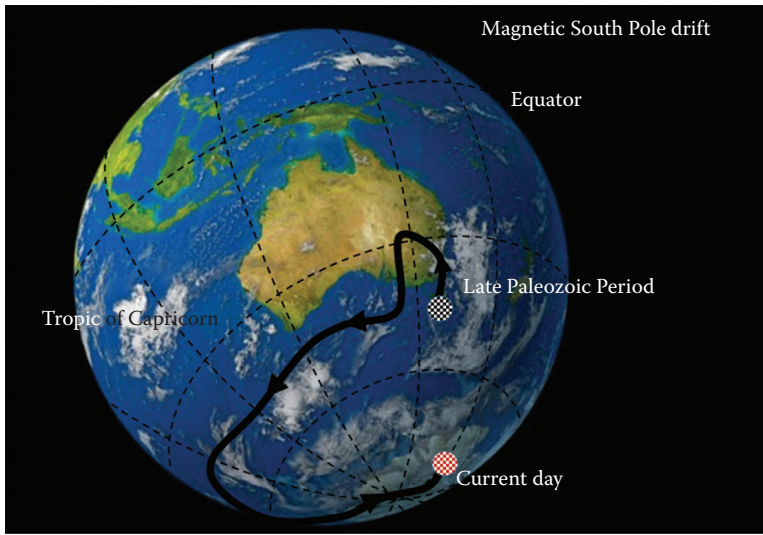
[astrophysics/astronomy, energy, geophysics] Study of the historical development and evolution of the Earth’s MAGNETIC field as permanently recorded in rocks, bricks, or clay. This study has revealed that the Earth’s magnetic field has changed direction (North–South) on the order of every several thousand years on a regular basis over the history of the EARTH. The Earth’s magnetic axis (magnetic North–South) can be described as having a “declination:” indicating the direction of MAGNETIC NORTH POLE with respect to the GEOGRAPHIC north pole; respectively “inclination:” the DISTANCE of the MAGNETIC AXIS to the geographic north pole.

$$\sin \lambda_p = \sin \lambda_\delta \cos p + \cos \lambda_\delta \sin p \cos D$$

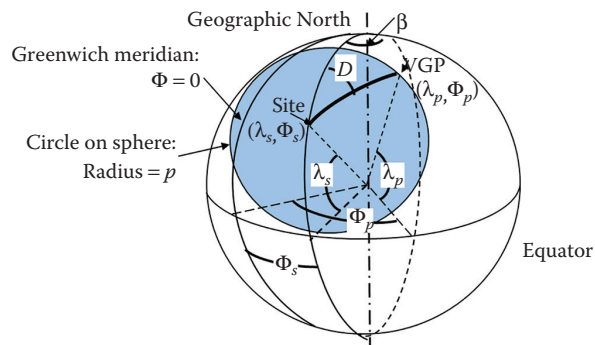
$$\Phi_p = \Phi_s + \beta; \text{ for } \cos p > \sin \lambda_\delta \sin \lambda_p$$

$$\Phi_p = \Phi_s + 180 - \beta; \text{ for } \cos p < \sin \lambda_\delta \sin \lambda_p$$

where $\sin \beta = \sin p \sin D / \cos \lambda_p$. Additional information obtained shows that the MAGNETIC POLES are generally wandering, disturbing the presumed fixed MAGNETIC FIELD lines across the globe, thus influencing the global position through magnetic compass and guidance systems (see MAGNETIC POLE and MAGNETIC DRIFT) (see Figure P.3).



(a)



(b)

Figure P.3 (a) Documented drift of South Pole over the past ~250 million years (b) Illustration of the concept and study of paleomagnetism.

Papin, Denis (1647–1712)

[general, mechanics, thermodynamics] French physicist and mathematician. Forerunner of the concept of the steam ENGINE with his invention of the concept of the PRESSURE COOKER also called a digester. The ideas of Papin inspired THOMAS SAVERY (1650–1715) to pursue his collaborative efforts in the development of the steam engine (see Figure P.4).



Figure P.4 Denis Papin (1647–1712) in 1689.

Parabola

[biomedical, computational] Symmetric graphical representation of a variety of mathematical expressions, but the most well known is the quadratic equation, for instance, mathematically expressed as $y = ax^2 + bx + c$, or $x = y^2$, respectively, in general notation: $Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$, where x and y are CARTESIAN COORDINATES and the remaining letters are constants. The parabola has an axis of symmetry that intersects with the graphical representation of the parabola in the vertex. The parabola is in the family of conic intersects: circle, ellipse, parabola, and hyperbola. In MECHANICS, the parabolic trajectory is well known and can be defined by the vector sum of the gravitational attraction and the propulsion force, where PROPULSION will be in vertical and horizontal directions. A horizontally released PROJECTILE (e.g., bullet from a gun) will have a vertical dependence on gravity (GRAVITATIONAL ACCELERATION g) as a function of time (t), describing only one side of the parabolic track defined as $y = -(1/2)gt^2$ (see Figure P.5).

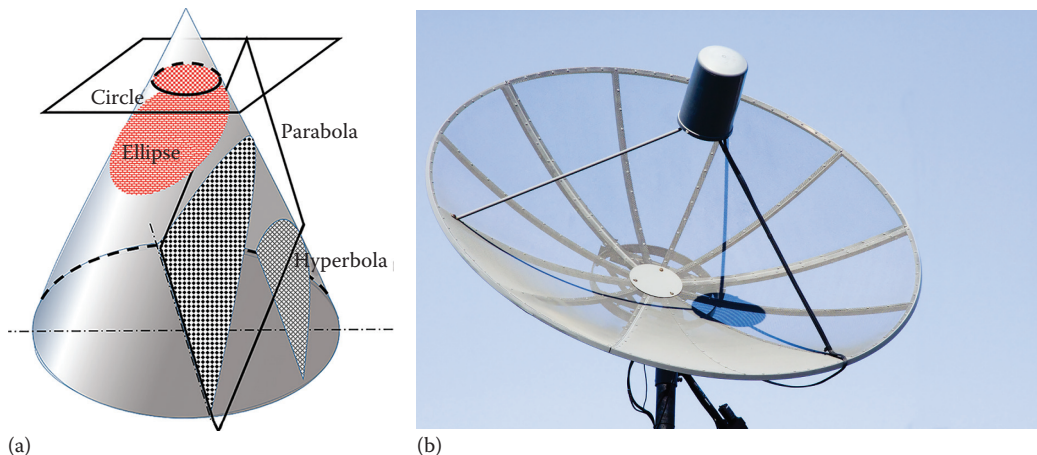


Figure P.5 (a) Parabola graph and (b) parabolic antenna.

Paracrine signaling

[biomedical, chemical, energy, general] Cellular uptake of signaling molecules, known as paracrine factors. Form of cellular communication, aimed at modifying the behavior of neighboring cells, short DISTANCE interaction only. Generally, the molecular constituents are self-terminating and have a short-lived impact.

This type of communication takes place in the early stage of cellular development. The following four specific communication pathways/receptor mechanisms can be identified: fibroblast growth factor (FGF) family, hedgehog family, TGF- β superfamily, and Wnt family. The concession is that the FGF family stimulates proliferation and differentiation, the hedgehog family of receptors affects protein assembly and other cellular process and has been shown to be instrumental in certain aspects of the proliferation of cancer processes, the TGF- β superfamily influences POLYPEPTIDE secretion and regulates cellular development, and the Wnt family of receptors has been shown to affect gene transcription, as well as influence the ACTIN and microtubular cytoskeleton next to the effects on transmembrane receptor function and the inhibition, respectively, assimilation of specific proteins (see [Figure P.6](#)).

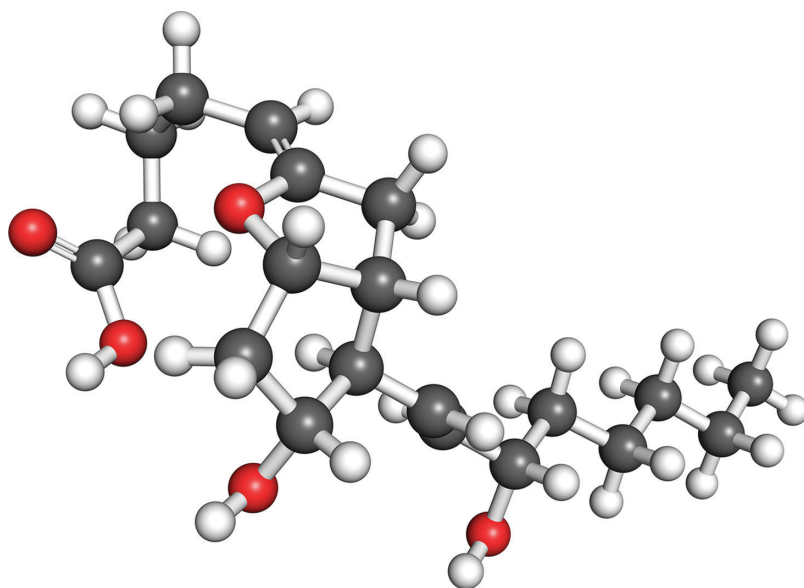


Figure P.6 Paracrine signaling function of prostacyclin hormone.

Parallel axis theorem

[general, mechanics] Theorem used to determine the moment of INERTIA of a rigid body about any axis, when the moment of inertia of the body about a parallel axis through the object's center of mass is known as well as the DISTANCE with respect to the perpendicular axes. Also known as the Huygens–Steiner theorem after the work of both the Dutch scientist CHRISTIAAN HUYGENS (1629–1695) and the Swiss mathematician Jakob Steiner (1796–1863). The MOMENT OF INERTIA (I) is now defined with respect to the distance between the off-center axis and the center of mass ($\square_{\text{cm}}$) axis, r , as $I = I_{\text{cm}} + mr^2$, where m is the mass of the object.

Parallel circuit

[general] Electrical components that are connected to operate in parallel to each other, groups of components that share at least one single common connection point. This stands in contrast to series circuits, where components operate in cascade. Electronic components are, for example, resistors, capacitors, inductors, diodes, transistors, operational amplifiers, and general INTEGRATED CIRCUITS (see [Figure P.7](#)).

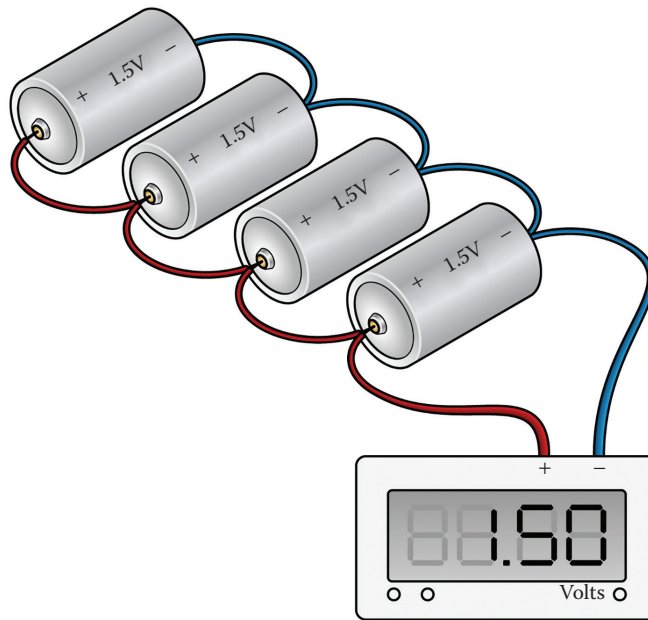


Figure P.7 Schematic of four dry-cell batteries in parallel circuit configuration, providing the same voltage as each individual battery.

Parallel processing

[acoustics, computational, theoretical] Functional process of simultaneously performing multiple operations or tasks. Parallel processing is used both for human cognition and in parallel computing by MACHINES. The brain in particular has the ability to simultaneously process multiple incoming stimuli, and respond to all or most of them. Parallel processing in the human brain has for instance particular relevance to VISION, HEARING, and touch. For other species, this may extend to smell just as much. In vision, the brain divides observations into four components: COLOR, depth, MOTION, and shape. These four perceptions are analyzed individually and compared to reference memories, in order to identify the observations. The brain then recombines all of this information into one image that you visually recognize and comprehend. Parallel processing of the brain may be linked to what is referred to as the Stroop effect. The Stroop effect is a seamless operation that takes place on a continual basis. Computational parallel processing refers to having multiple algorithms work simultaneously, often splitting a program in its functional components. The computational processes will be run on individual separate electronic processors (central processing unit [CPU]). On a more elaborate level, several programs can run simultaneously in a single unit (i.e., computer) or on multiple computers electronically linked together in a cluster (cluster computing), which requires specialized software to function correctly, referred to as “distributed processing software.” Concurrency is a term used in communications for operating systems and databases referring to the condition where multiple tasks remain logically active and simultaneously advancing in the process by interleaving the execution order of the tasks. Concurrency actually merely creates the illusion of simultaneously executing instructions.

Parallel-plate capacitor

[electronics, general] Two charge carrying plates, with area A , separated by a fixed DISTANCE d , at opposite and equal charge (charge density σ_{charge}) form a CAPACITOR with capacitance $C = \epsilon_0 A/d$, where $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{N m}^2$ is the permittivity of free space, which is altered when a medium is inserted with a different permittivity (ϵ), ignoring boundary effects. The electric field between the two plates is

$E = \sigma_{\text{charge}} / \epsilon_0$. Parallel-plate capacitors provided a popular tuning mechanism for analog RADIO operation (see CAPACITOR) (see Figure P.8).

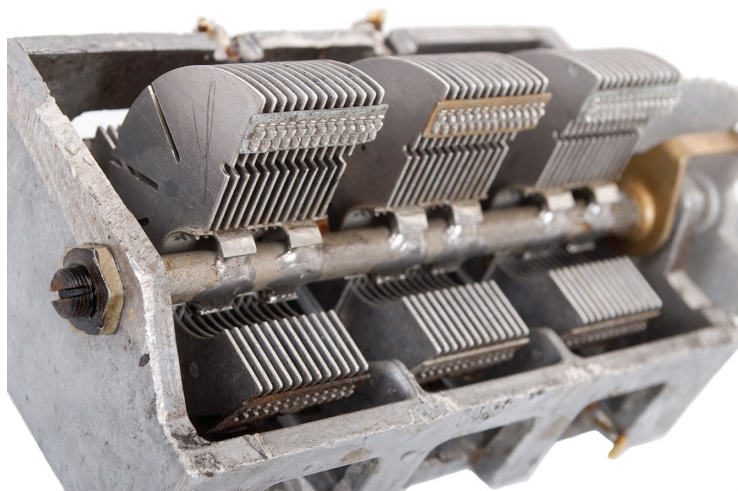


Figure P.8 Electrolytic parallel-plate capacitor rolled up into tuning capacitor (variable parallel-plate capacitor) that adjusts the resonant frequency of a circuit by means of changing the surface area of the capacitor when turning the dial.

Parallel-plate fluid flow

[fluid dynamics] Two-dimensional LAMINAR FLOW process that will exhibit primarily the effects of shear stresses. The shear stress at the wall (τ) can be derived from the Navier–Stokes equations and the CONTINUITY EQUATION: $\tau = 6Q\eta_{\text{dyn}}/wb^2$, where the FLOW rate (Q) and plate separation or height (b) are the determining factors as is the width of the flow chamber (w), where η_{dyn} is the DYNAMIC VISCOSITY. The flow velocity v_x can be used to solve for the Navier–Stokes and continuity equations: $-(dP/dx) + \eta_{\text{dyn}}(\partial^2 v_x / \partial y^2) = 0$; $-(dP/dy) + \rho g_y$; $-dP/dz = 0$, where P is the pressure and g_y the GRAVITATIONAL ACCELERATION. The volume flow rate follows from POISEUILLE'S LAW and can be derived as the integral over the cross-sectional area: $Q = -w(2b^3/\eta_{\text{dyn}})(\partial P/\partial x)$. A special case is COUETTE FLOW, for instance relevant to LUBRICATION for a rotating axle in a housing (e.g., piston-bar on camshaft) (see Figure P.9).

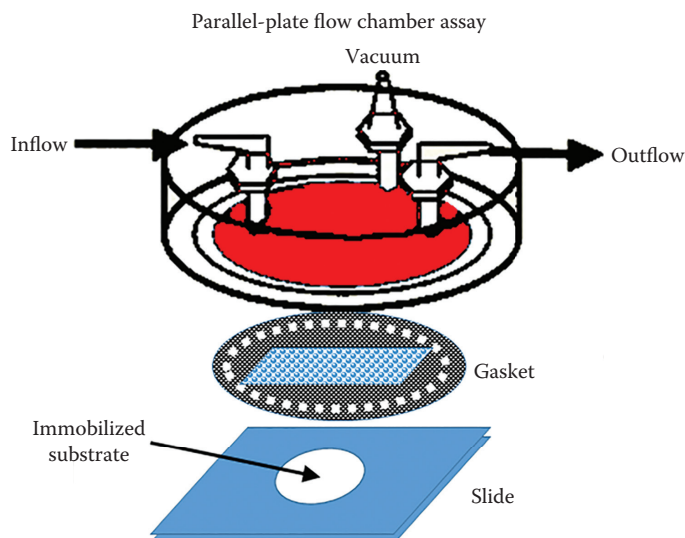


Figure P.9 Parallel-plate fluid flow for an automated flow chamber assay.

Paramagnetic substances

[general] Magnetic material that under free space conditions has randomly oriented MAGNETIC dipoles, which can be aligned under the influence of an external MAGNETIC FIELD. The total magnetic field in the paramagnetic material under the influence of an external magnetic field ($\vec{B}_0$) is $B = B_0 + B_m = (1 + \chi)\mu_0 nI$, where $B_m = \chi B_0$ is the induced field with χ the magnetic susceptibility for the paramagnetic medium in case the external field is provided by a SOLENOID, I is the current, n is the number of windings, and $\mu_0 = 4\pi \times 10^{-7}$ H/m is the permeability of free space. For instance, for aluminum, $\chi_{Al} = 2.2 \times 10^{-5}$; for AIR, $\chi_{air} = 3.6 \times 10^{-7}$; and for water, $\chi_{water} = -9.12 \times 10^{-6}$.

Paramagnetism

[atomic, nuclear] The congruent lining up of the internal MAGNETIC FIELD within a solid body under the influence of exposure to an external magnetic field. The opposite is known as DIAMAGNETISM. Substances that have internal magnetic (DIPOLE) moment are sensitive to external magnetic fields as described by the MAGNETIC SUSCEPTIBILITY. The tendency of the internal magnetic dipoles to line up with an applied external magnetic field will generally be countered by the thermal agitation, which in turn continuously randomizes the individual magnetic dipoles. The partial alignment and resulting proportional increase in the total magnetic field was described by PAUL LANGEVIN (1872–1946).

Parametric acoustic array

[acoustics, computational] Directional transmitter and receiver configuration described based on WAVE propagation in an ideal FLUID that has no heat conduction and viscosity. The description involves nonlinear acoustical wave propagation described in accordance with the Lighthill equation as $(\partial^2 \rho / \partial t^2) - C_0^2 \nabla^2 \rho = -C_0^2 \square^2 \rho = (\partial^2 / \partial x_i \partial x_j) \mathbb{T}_{ij}$, where $\mathbb{T}_{ij} = \rho u_i u_j + P_{ij} - C_0^2 \rho \delta_{ij} + D_{ij}$ (D_{ij} the respective viscous stresses, P the pressure, i and j the reference frame directional subscripts (orthogonal), ρ the density, u the velocity, and C_0 a constant related to the acoustic AMPLITUDE) and $\nabla^2 = \nabla \cdot \nabla = \sum_{i=1}^n \partial^2 / \partial x_i^2$ is the Laplace operator. The collected “INTERFERENCE” pattern for the ACOUSTIC INTENSITY as a function of ANGLE (θ) is now relatively similar to the atomic RUTHERFORD SCATTERING, observed as the scattered (Δ_j) ANGULAR FREQUENCY $\omega_s = v_s 2\pi$, with v_s the acoustic frequency for a collimated beam with CROSS SECTION S_0 , retrieved from DISTANCE R_0 . The acoustic intensity distribution for the parametric array is described as $I_a = \omega_s^4 P_0^4 S_0^2 / 2 (8\pi)^2 \rho_0^3 C_0^9 \{1 + (1/2)(\rho_0 / C_0^2)(d^2 P / d\rho^2)_{\rho=\rho_0}\}^2 * \{1/R_0^2 [\alpha^2 + k_s^2 \sin^4((1/2)\theta)]\}$, where $\omega_s = \omega_2 - \omega_1$, with ω_1 the incident and ω_2 the re-emitted wave frequency; $k_s = \omega_s / C_0$; and $\alpha \sim$ scattering probability the “attenuation coefficient” (see ULTRASOUND) (see Figure P.10).



Figure P.10 Example of a parametric acoustic ultrasound imaging probe array.

Parasympathetic nerve system

[biophysics, chemical, energy] The human autonomic nerve system is divided into two distinct functional areas: sympathetic and parasympathetic. The autonomic nerve system and the categorization into sympathetic, parasympathetic, and enteric systems managing the intestinal tract were introduced by John Newport Langley (1852–1925), a physiologist from Great Britain. The autonomic nerve system is the part of the nerve system that controls visceral functions: breathing, digestion, HEART function and heart rate, perspiration, pupillary dilation, respiratory rate, salivation, swallowing, sexual arousal, and urination, to name a few, and supports consciousness. The sympathetic nerve system controls the response to stimuli (e.g., “flight or fight”) and maintains HOMEOSTASIS. The parasympathetic nerve system specifically manages the bodily maintenance such as defecation, digestion, salivation, sexual arousal, tear production (emotion), and urination (see Figure P.11).

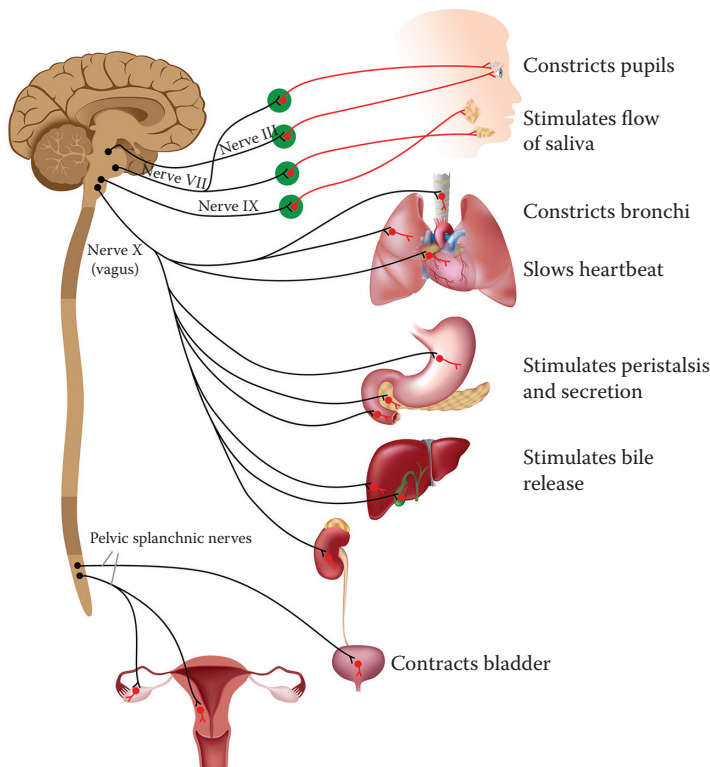


Figure P.11 Illustration of the configuration for the parasympathetic nerve system.

Paraxial approximation

[acoustics, computational, optics] Ray-tracing SOLUTION in the regime of small ANGLE with respect to the main axis, generally the following holds: $\sin \xi \approx \xi$; $\tan \vartheta \approx \vartheta$; $\cos \xi \approx 1$. In OPTICS, this is the Gaussian approach or first-order approximation, tracing the beam as quasiparallel paraxial rays. In ACOUSTICS, the paraxial approximation considers the ultrasound TRANSDUCER beam, emitted as a SPHERICAL WAVE, and

approximates it as a quasiplanar wave assuming that the majority of sound is propagating in a fixed x -direction, and the AMPLITUDE profile can then be described by means of a diffraction correction term: $P = \partial v v_0 C(x, y, z, \omega) e^{i(kx - \omega t)}$, where v is the propagation velocity, $C(x, y, z, \omega)$ is the correction term, ANGULAR FREQUENCY $\omega_s = v_s 2\pi$, with v the acoustic frequency, P is the pressure, $\partial = \sqrt{(y^2 + z^2)}$ is the average critical dimension, and $k = 2\pi/\lambda$ is the wavenumber for wavelength λ (see Figure P.12).

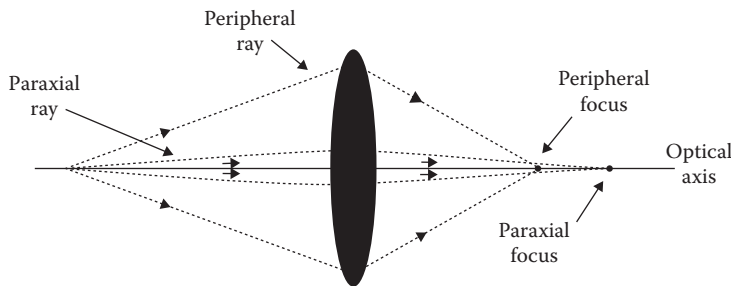


Figure P.12 Paraxial rays in image formation.

Parent nucleus

[atomic, biomedical, general] In biology, this refers to a NUCLEUS in CELL division, which divides and produces two or more daughter nuclei. In atomic PHYSICS, this refers to RADIOACTIVE DECAY, where the parent nucleus (parent RADIONUCLIDE or parent RADIOISOTOPE) is the originating nucleus that decays with emission of ENERGY or particles, for instance, ^{238}U , the uranium parent for ALPHA DECAY with thulium as the “daughter.” More specifically, in nuclear decay the process refers to the components as nuclides (*also see* PARENT NUCLIDE).

Parent nuclide

[nuclear] In RADIOACTIVE DECAY, the parent nuclide can be long lived compared to daughter, or short lived. The parent can be naturally occurring or requires nuclear bombardment for formation. An ATOM is the smallest stable unit of an ELEMENT in existence. Each atom of the respective element consists of a certain number of electrons, protons, and neutrons, which define a nuclide and its chemical properties. These particles were discovered in the early 1900s and define modern atomic theory. Under the condition of decay, there are the following examples of naturally occurring long-lived parent nuclides: ^{86}Rb (rubidium), ^{100}Pd (palladium), ^{232}Th (thorium), ^{235}U (uranium), and ^{238}U (uranium); and artificially produced nuclides: ^{68}Ge (germanium; stable 270 days), ^{82}Sr (strontium; stable 25.6 days), and $^{188}_{74}\text{W}$ (tungsten; stable 69 days) all used in POSITRON EMISSION TOMOGRAPHY (PET). The NUCLIDE of certain atomic species are characterized by specific numbers of protons and neutrons (both called nucleons), representing the constitution of its NUCLEUS. The term nuclide was proposed in 1947 by Truman P. Kohman (1916–2010), referring to a species

of nucleus. Nuclides with the same atomic number (number of PROTON), but different NEUTRON numbers, are defined as isotopes of this element (*also see* PARENT NUCLEUS) (see Figure P.13).

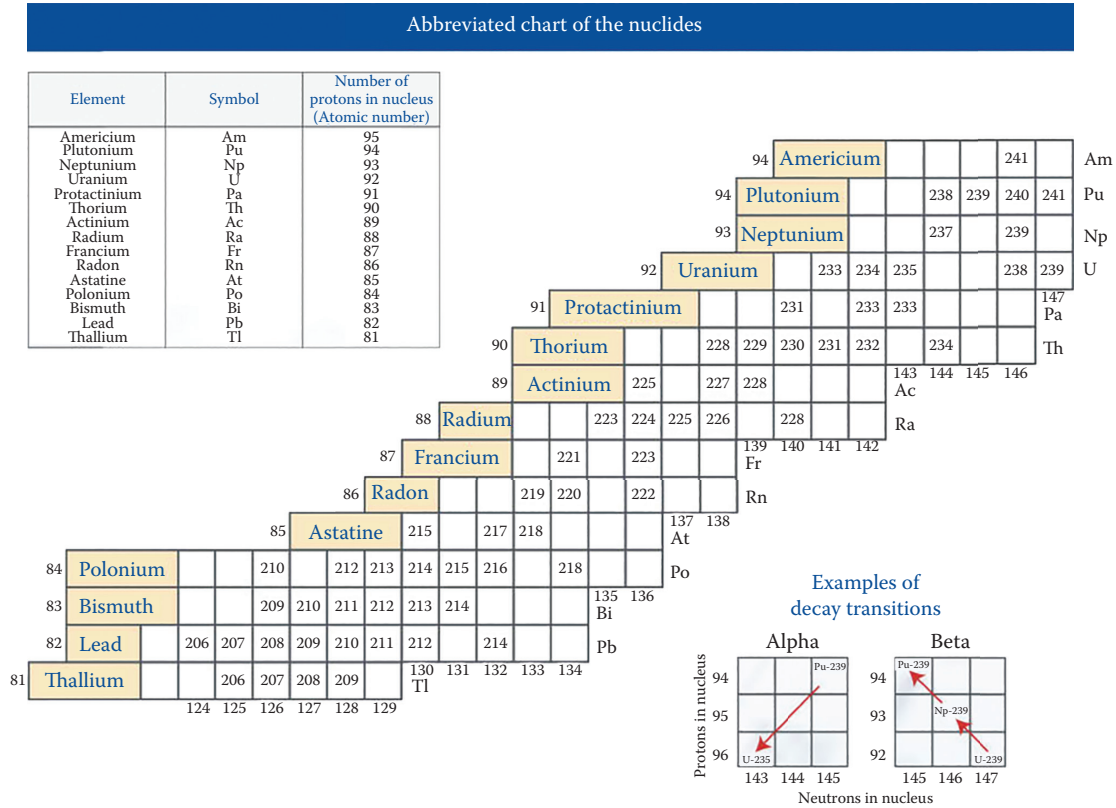


Figure P.13 Parent nuclide concept: chart of nuclides. (Courtesy of American Nuclear Society.)

P

Parity

[atomic, computational, nuclear, quantum, solid-state] Property describing the characteristic state of a phenomenon, specifically the equality between conditions or the condition being odd or even, particularly referencing the quantum-mechanical state. The scientific implications of parity range from ELEMENTARY PARTICLES to the NUCLEUS and the wavefunction. For elementary particles, the “intrinsic parity” defines the conditions for conservation. The intrinsic parity conforms to an integer number +1 or −1, which is assigned to each individual elementary PARTICLE in such a way that the product of the parities of all the particles in a system, multiplied by the parity of the wavefunction, which describes the entire system, remains unchanged when particles are formed (created) or annihilated. For elementary particles (BARYONS, antibaryon, QUARK, antiquark), both strangeness (QUANTUM NUMBER: strangeness: S) and parity are conserved under strong (nuclear) interaction; however, weak interactions are exempt. Quarks have a defined intrinsic parity +1 and a defined antiquark parity −1. Nucleons, in general, have a defined intrinsic parity +1. In a complex system of a MESON with quark (“ q ”) and antiquark (“ $\bar{q}$ ”), assuming antiparallel spins ($s = 0$), yields for parity $P = P_q P_{\bar{q}} (-1)^\ell$, where ℓ is the orbital angular quantum number. The meson parity is defined as $P = -(-1)^\ell = (-1)^{\ell+1}$. For the nucleus, parity is associated with the TOTAL ANGULAR MOMENTUM quantum number (I), generally provided as superscript to the total angular momentum quantum number in denomination “+” or “−” (or “+1” associated with even orbital quantum number, and “−1” associated with odd orbital quantum number), as a multiplicative quantum number. Nuclear DECAY involving beta emission generally does not conserve parity. Nuclear states are identified as having both an intrinsic SPIN and a

well-defined parity, which is a function of the wavefunction for all the nucleons. The behavior of wavefunction of the nucleons under reversal of their coordinates, taking the origin at the center of the nucleus, will define the parity of the nuclear system. The parity of the WAVEFUNCTION (Ψ), which also applies to photons, is a property of symmetry as well, positive parity: $\Psi(x) = \Psi(-x)$, and negative parity: $\Psi(x) = -\Psi(-x)$. The wavefunction parity can be traced to the Hermite polynomials as a SOLUTION to the quantum-mechanical problem of the harmonic oscillator, using the PRINCIPAL QUANTUM NUMBER (n). Parity violation comes into play based on the fact that conservation of nuclear parity relies on the assumption that potentials involved in nuclear transitions are MIRROR symmetric. Nuclear conditions that are not symmetric and have loss of parity are considered to possess helicity, since a helix is not mirror symmetric (e.g., a human is not MIRROR symmetric on the MACROSCOPIC scale). Purely mathematically, parity is the fact whether an observation or a quantity is odd or even. Mesons have a specific parity, referred to as G-PARITY (see [Figure P.14](#)).



Figure P.14 Illustration of the concept of parity as a “condition” with opposite configuration.

Parity conservation rule

[atomic, nuclear, quantum, solid-state] In beta DECAY, the change in PARITY is $\Delta\pi_p = (-1)^{L_\beta}$ and the parity conservation rule accounts for this as $\pi_p = \pi_D (-1)^{L_\beta}$.

Partial pressure, Dalton's law of

[thermodynamics] See DALTON'S LAW.

Partial pressure of a constituent

[thermodynamics] The pressure of a GAS in a GAS MIXTURE (P_i) or as dissolved in LIQUID. In atmospheric AIR, there are several gasses with nitrogen the dominant component at 1 atmosphere ($1 \text{ atm} = 1.01325 \times 10^2 \text{ kPa}$) and normal temperature (293 K) holding $0.78 \text{ atm} = 7.90335 \times 10^1 \text{ kPa}$. For BLOOD, the partial pressure of oxygen is important for biological and physiological functions and efficacy of the metabolic reactions. One specific example is in the binding of oxygen to hemoglobin. The binding of oxygen to the protein LIGAND in hemoglobin can be described by the HILL EQUATION (*also see* DALTON'S LAW [of partial pressures]) (see Figure P.15).

Characteristic binding of O_2 with hemoglobin

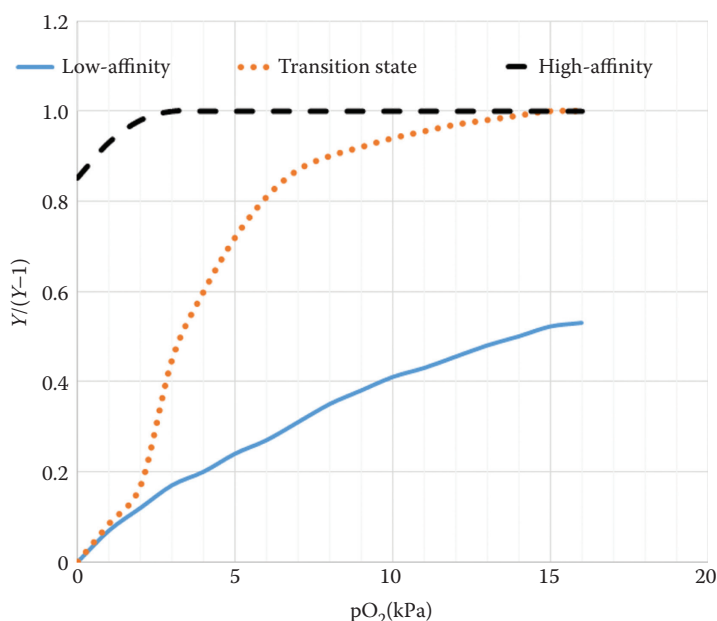


Figure P.15 Graphical representation of the partial pressure concept.

Particle

[atomic, general, solid-state] Any MACROSCOPIC or MICROSCOPIC unit that is considered to be one piece. On a macroscopic scale, dust particles and RAIN drops are examples of a broad scale of presumably solid items, which specifically move as one object with respect to the external observer. The relative size of the object defines it as either a particle or an object; generally particles are less than a millimeter in diameter. On a microscopic scale, the particles range from molecules to atoms, electrons, protons, neutrons to elementary

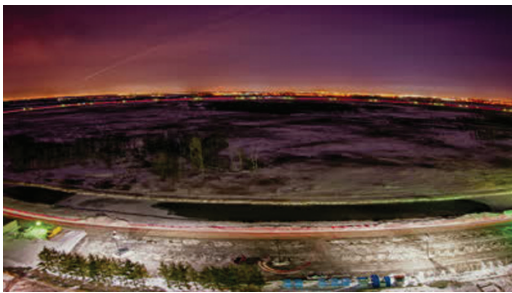
particles of leptons, mesons and BARYONS, as well as respective antiparticles. Technically, a PHOTON is also considered a particle for a range of interactions (see [Figure P.16](#)).



Figure P.16 Concept of particles in air.

Particle accelerator

[atomic, general, nuclear] CYCLOTRON developed by ERNEST LAWRENCE (1901–1958) in 1934. Device for acceleration of charged particles such as protons, deuterons, and alpha particles under the influence of a MAGNETIC FIELD. The conduit used for the PARTICLE trajectory consists of a METAL tube that has two halves that are formed in the shade of opposite facing Ds, called “Dees,” where the path forms a continuous loop. Particles are injected under the influence of an external electric field, after which they experience a magnetic field inside the D-shaped tube. The maximum velocity ($v_{\max}$) obtained is a function of the radius of the cyclotron (R), the magnetic field strength (B), the respective particle charge (q), and the MASS (m) of the particle: $v_{\max} = q(BR/m)$, which will be ejected from the cyclotron, for instance to initiate a collision, with kinetic ENERGY: $(1/2)mv^2 = (1/2)q^2(B^2R^2/m)$, which can reach or exceed 30 MeV, above which relativistic effects start being introduced, for instance an increase of the period of the phenomenon as a function of radius. The classical MECHANICS period is $T = 2\pi m/qB$, for a particle moving in a circle with radius: $r = mv/qB$. Cyclotrons are nuclear colliders, for instance producing radioactive isotopes, next to FISSION and FUSION experimentation. The cyclotron in Batavia, IL, USA, has a diameter of 1.5 km, supporting research at the Fermi Laboratories. Other LINEAR ACCELERATORS (SYNCHROTRON) are also used for similar experimentation, for instance the Stanford, CA, USA accelerator is 3.3 km long and relies on an electric field along the length of the accelerator, harmonically fluctuating over the length of the evacuated tube, providing kinetic energies up to 50 GeV (see [Figure P.17](#)).



(a)



(b)

Figure P.17 (a) Areal view of a particle accelerator and (b) large hadron collider particle accelerator aerial view.

Particle accelerators, linear

[atomic, nuclear] *See* SYNCHROTRON.

Particle imaging velocimetry (PIV)

[fluid dynamics] Noninvasive optical laser imaging technique used in research and diagnostics of combustion processes, flow, MICROFLUIDICS, spray atomization as well as TURBULENCE. The PARTICLE concept relies on the use of “tracer” particles for tracking, combined with LIGHT delivery and imaging in a “single sheet” within the flow. The imaging process relies on a cross-correlation technique for “particle tracking.” Standard, MACROSCOPIC PIV uses imaging arrays and particularly “time-resolved” CMOS cameras in combination with laser scanning, while lab-on-a-chip devices are used in MICROSCOPIC imaging. PIV measures whole velocity fields by taking multiple consecutive images within approximately 6–10 ns time frame. The IMAGE processing calculates the DISTANCE and trajectory of individual particles within the image interval time. Based on the measured displacement over the time difference, the localized velocity can be calculated. Because of the anticipated fast flow, blurring needs to be avoided, which requires the use of fast laser pulses. Additionally, laser light can be focused into a thin light sheet, allowing only particles in a single plane to be imaged. The use of a high-speed CAMERA can rapidly store the first frame to subsequently acquire additional exposures (see [Figure P.18](#)).

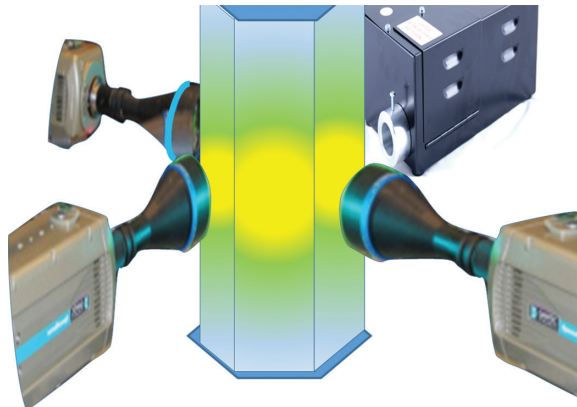


Figure P.18 Particle imaging velocimetry design of experiment. Flow created in a transparent water channel is seeded with light-reflecting particles. The particulate solute are illuminated by a laser and the images of migration is captured by means of a high-resolution camera. The collected tracks of the particle flow derived from sequential images are processed to yield the volumetric instantaneous flow velocity measurements.

Particle in potential well

[nuclear] *See* SHELL MODEL.

Particle theory of light

[general, optics] Documented model of LIGHT by SIR ISAAC NEWTON (1642–1727) in 1704, describing light as small particles. The concept itself actually dates back to early Greek and Persian descriptions, specifically REFLECTION. In Newton’s description, refraction is also captured as the interaction of a PARTICLE at the surface of a medium, where it experiences a brief attractive force towards the medium, increasing the vertical component of the particle’s velocity. Since the particle is not exposed to any net horizontal forces, the resulting horizontal vector component of the velocity will remain constant. On the COLOR aspects, Newton also hypothesized that the mass of the light particle varied with color. RED light particles are heavier than violet. In refraction the red particle will experience a greater attractive force; hence the refraction ANGLE will be greater, thus explaining the workings of a PRISM. In order to account for POLARIZATION effect, Newton

postulated that light particles cannot be spherical. In order for polarization to be possible, the particles should either be plate-like or at least have “sides,” deviating from spherically symmetric (see [Figure P.19](#)).



Figure P.19 Illustration supporting the particle theory of light; a male “Great Tit” from the Paridae family of birds observing itself in the reflection from the water as we see both bird and image. The reflection can be described through the path of photons acting as tennis balls interacting with the reflective surface.

Particle tracking velocimetry (PTV)

[fluid dynamics] Technique to measure **PARTICLE** velocity, specifically applied to fluid-dynamic applications. This kind of **IMAGE** analysis algorithm is available in the tool kits of several commercial **SIGNAL** analysis software packages, often based on a Lagrangian reference frame (*also see* **PARTICLE IMAGING VELOCIMETRY**).

Partition coefficient

[biomedical, chemical] The ratio of the respective concentrations of a compound in an amalgam of two immiscible phases (e.g., two liquids, or a mobile with respect to a stationary **PHASE**, generally pertaining to the solubility of one **LIQUID** in another) while maintained at an **EQUILIBRIUM STATE**.

Partition function

[computational, mechanics, thermodynamics] Simple systems can be partitioned based on their respective quantum or energy states (E_i), which will follow the partition function: $Z_{\text{part}} = \sum_i e^{-\beta_T E_i}$, where $\beta_T = 1/k_b T$ is the “inverse temperature,” with $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann coefficient, and T the temperature in kelvin. For the harmonic oscillator, this becomes, based on the energy $E = [n + (1/2)]\hbar\omega$, $Z_{\text{part}} = e^{-(1/2)\beta_T \hbar\omega} / (1 - e^{-\beta_T \hbar\omega})$, where $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ is **PLANCK’S CONSTANT**, $\omega = 2\pi\nu$ the **ANGULAR VELOCITY**, ν the frequency, and n the **QUANTUM NUMBER**. On a mathematical basis, specifically in **PROBABILITY** theory, this also refers to a configuration integral, as a generalization, using the Hamiltonian (H) representing the potential function (which is measurable, is an observable): $Z_{\text{part}}(\beta_T) = \int \exp\{-\beta_T H(x_1, x_2, x_3, \dots)\} dx_1, dx_2, \dots$. Specific applications are in information science, **SIGNAL** processing, and pertaining to dynamical systems. In statistical **MECHANICS**, the free entropies of a system can frequently be expressed as the **LOGARITHM** of a partition function, specifically for the **ONSAGER RECIPROCAL RELATIONS**. In thermodynamic systems, the Onsager reciprocal relations are used to express the equality of particular ratios between forces and flows that are not specifically in equilibrium; however, local equilibrium may exist under strict boundary conditions.

Pascal (Pa)

[fluid dynamics, general] unit of pressure $1 \text{ Pa} = 1 \text{ N/m}^2$, named in honor of the groundbreaking work for standardizing pressure assessment by BLAISE PASCAL (1623–1662).

Pascal, Blaise (1623–1662)

[fluid dynamics, thermodynamics] Scientist, physicist, and mathematician from France. The work of Pascal is primarily known in FLUID DYNAMICS with respect to pressure, to which he lend his name as the unit for pressure. Other works of Pascal in the mathematical field are his contributions to the principle of probability as a contribution to the work of PIERRE DE FERMAT (1601–1665) (see [Figure P.20](#)).

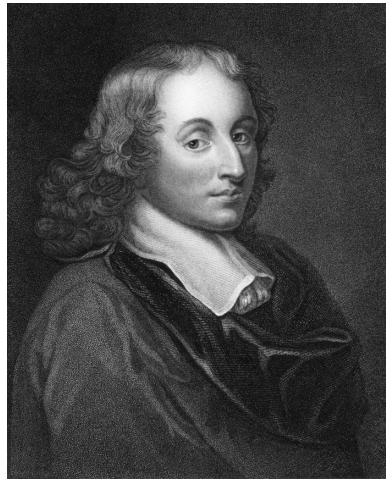


Figure P.20 Blaise Pascal (1623–1662), engraved by H. Meyer.

Pascal, law of

[thermodynamics] See LAW OF PASCAL.

Pascal's law

[fluid dynamics] Mechanism of pressure operating in all directions. When in any point in a confined fluid there is an increase in pressure, there is an immediate and equal increase in pressure at every other point within the FLUID in the container that holds the fluid.

Pascal's principle

[fluid dynamics, general] The pressure applied to a FLUID is transferred equally and uniformly throughout the entire fluid. (described in the treatise of BLAISE PASCAL [1623–1662] “On the Equilibrium of Liquids,” approximately 1651). In his treatise, Pascal recognized that with force applied to a liquid, the DISTANCE traveled by the LIQUID and the applied force were linearly proportional irrespective of the surface area. In this manner, force can be scaled in a similar manner to a LEVER, using the hydraulic force applied over a larger area to be transferred proportionally to the ratio of the respective surface areas. The hydraulic LIFT provides the

most common example for this (fluid examples: water, oil). Hydraulic systems use incompressible fluids, whereas pneumatic systems use compressible fluids (e.g., AIR or gasses in general) (see [Figure P.21](#)).



Figure P.21 Hydraulic lift (automobile jack) working based on the Pascal principle, transferring force based on the surface area of the fluid column.

Paschen, Friedrich (1865–1947)

[atomic, nuclear, quantum] Physicist from Germany, dedicated to electro-optics. The PASCHEN LINES for hydrogen discharge (1908) are a key result of his work as well as other theoretical descriptions for electrical IONIZATION effects (see [Figure P.22](#)).



Figure P.22 Friedrich Paschen (1865–1947).

Paschen law

[atomic, nuclear] Also **Paschen's Law**. The breakdown voltage ($V_{\text{excitation}}$) for a GAS in a pressurized vessel exposed to electrical discharge will reduce in MAGNITUDE proportional to the gap (d) between the ANODE and CATHODE and the partial PRESSURE (p): $V_{\text{excitation}} = f(p, d)$, described by FRIEDRICH PASCHEN (1865–1947) in 1889. PASCHEN'S LAW reflects the atomic breakdown described by JOHN SEALY TOWNSEND (1868–1957). Townsend's work involved the analysis of the cascade effect of colliding electrons in an electrical discharge in gas between two electrodes, where the secondary electrons are gaining ENERGY under the influence of the applied electric field resulting in additional excitation effects induced by collision, providing enhanced IONIZATION (see [Figure P.23](#)).

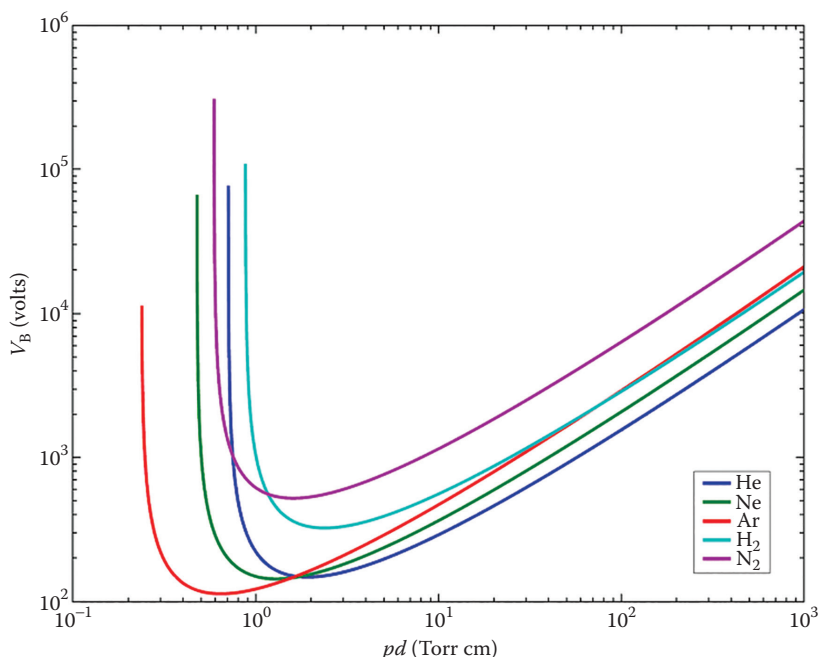


Figure P.23 Paschen curves representative of the Paschen law.

Paschen lines

[atomic, general] See **PASCHEN SERIES**.

Paschen series

[atomic, general, nuclear] ATOMIC EMISSION wavelengths (λ), respectively, FREQUENCY (ν), as derived by FRIEDRICH PASCHEN (1865–1947), in particular for hydrogen, based on the BOHR ATOMIC MODEL transitions between electron orbits (n_i): $\nu = m_e c^4 Z^2 / 8 \epsilon_0^2 h^3 \left[(1/n_1^2) - (1/n_2^2) \right]$, for $n_1 = 3$, where $m_e = 9.10939 \times 10^{-31} \text{ kg}$ is the electron mass, $e = 1.60217657 \times 10^{-19} \text{ C}$ the charge equivalence of an electron [–] (or respectively, PROTON [+]), the permittivity of free space $\epsilon_{\text{EM0}} = 8.85419 \times 10^{-12} \text{ C}^2/\text{N m}^2$, PLANCK'S CONSTANT $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, Z the number of charges in the NUCLEUS, and n_2 the respective originating electron orbits. Note that $n_1 = 1$ represents the LYMAN SERIES, $n_1 = 2$ is the BALMER SERIES, $n_1 = 4$ yields the Brackett series, and $n_1 = 5$ the Pfund lines, where $n_2 > n_1$ (see [Figure P.24](#)).

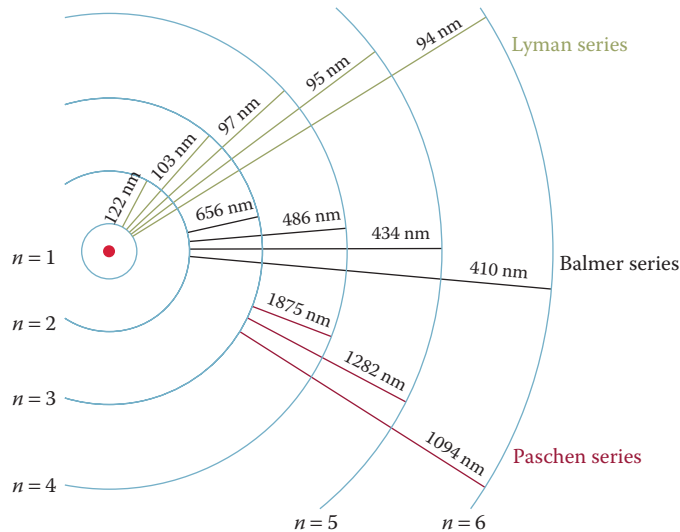


Figure P.24 Paschen line emission spectrum.

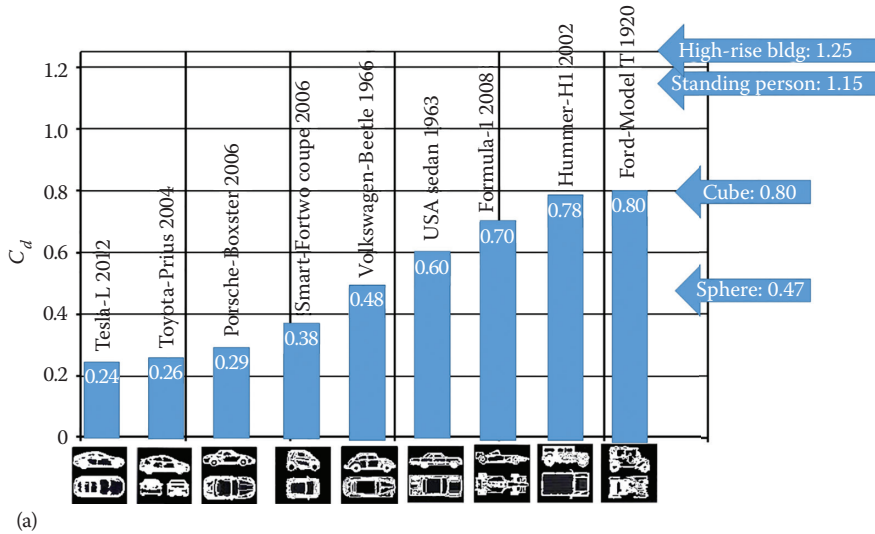
Paschen–Back effect

[atomic, general, nuclear, quantum] The coupling of the L -vector (total orbital momentum) and the S -vector (spin angular momentum) (i.e., RUSSELL–SAUNDERS COUPLING) regarding atomic transitions under the influence of very strong external MAGNETIC FIELD. In contrast, the absence an external magnetic field provides the “normal ZEEMAN EFFECT,” whereas a weak magnetic field induces the anomalous Zeeman effect. The Paschen–Back effect only affects changes in the L and m_L , completely neglecting the SPIN influences, as described by FRIEDRICH PASCHEN (1865–1947) and ERNST EMIL ALEXANDER BACK (1881–1959). The Paschen–Back effect resembles the normal Zeeman effect under restrictions of the “LANDE’S G-FACTOR” being 1: $\Delta E = \left(\frac{e\hbar}{2m_e} \right) m_j B$, where $e = 1.60217657 \times 10^{-19} \text{ C}$ is the electron charge equivalent, $\hbar = h/2\pi$, with PLANCK’S CONSTANT $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, electron mass $m_e = 9.10939 \times 10^{-31} \text{ kg}$, m_j the QUANTUM NUMBER for the TOTAL ANGULAR MOMENTUM, and B the external magnetic field (*also see ZEEMAN EFFECT*).

Passenger car, drag coefficient

[fluid dynamics, mechanics] Automobile, two axles and four wheels propelled by gasoline, diesel, ELECTRICITY, natural GAS, or fuel cells. The DRAG COEFFICIENT of an automobile pertains to its AERODYNAMICS, and interrelated to its fuel economy (fuel consumption). Items that influence the aerodynamic properties are deviations from a perfectly smooth surface, such as a roof rack, curvature on the front and rear, as well as door-handle grips and windshield wipers, next to mudflaps behind the wheels and the encasing of the wheels, and also the definition of a front and rear “spoiler” makes an impact. The final design components that influence the drag are the length, height and width of the car, and the inherent frontal surface area (A), next to the velocity of both the independent airflow and the automobile PROPULSION, combined (v_{flow}); note that turbulent or LAMINAR FLOW will influence the final interaction, providing lower drag under turbulent flow. The drag coefficient (C_d) is derived from the resisting force ($F_d = C_d \left(\frac{\rho v_{\text{flow}}^2}{2} \right) A$) as $C_d = 2F_d / \rho v_{\text{flow}}^2 A$, where ρ represents the density of the FLUID in which the object is moving (i.e., AIR). The smaller the number the more aerodynamic the object. The power (e.g., horsepower) required to overcome the drag is $\dot{W} = F_d v_{\text{flow}}$. In addition to these factors, the REYNOLDS NUMBER also contributed to the final outcome of the influence of flow on the MOTION: $\text{Re} = v_{\text{flow}} L / \eta_{\text{visc}}$, where η_{visc} is the viscous RESISTANCE and L the characteristic length, meaning that the longer the automobile the more likely the flow along the body will be laminar. For $\text{Re} > 47$, BOUNDARY LAYER separation will take place, hence influencing the fluid resistance experienced by the body. Lowest COEFFICIENT OF DRAG on record for a production automobile at the

time of assembly of this record is the Mercedes CLA with $C_d = 0.23$, compared to that for a Ford Model T that resembles the drag of a cube at $C_d = 0.80$. Note that nonproduction automobiles may have superior values for drag coefficients in the front and side direction, but these are special cases, such as Formula One race cars (see Figure P.25).



(a)



(b)

Figure P.25 (a) Automobile drag coefficient and (b) Formula One race car with adjustable drag coefficient through adjustment of flaps and airfoils by means of remote control based on the on-the-fly measured road and air-flow conditions.

Passive resistance

[thermodynamics] States of equilibrium and the associated settings can respond to a change while meeting with a certain RESISTANCE, which has been termed passive resistance, based on the direction in which it acts. These equilibrium situations can generally be unstable. This instability will cause a potentially violent response and a respective change to an often very small disturbance. The disturbance in this case is small compared to the quantities within the system (*also* “inertia resistance”).

Passive state

[thermodynamics] Thermodynamic state that does not produce work (*also see* CANONICAL STATE).

Pauli, Wolfgang Ernst (1900–1958)

[atomic, computational, general, nuclear] Scientist and theoretical physicist from Austria. His work contributed to the understanding of the BOHR ATOMIC MODEL, and also to the formation and understanding of the WAVE MECHANICS principles in QUANTUM MECHANICS, associating wave theory with electron orbits (sometime referred to as “electron optics”), yielding stability conditions for electron orbits, limiting the number of electrons occupying a certain ENERGY level. The work of Pauli started out in 1925 in sync with the work of WERNER KARL HEISENBERG (1901–1976), ERWIN SCHRÖDINGER (1887–1961), and PAUL DIRAC (1902–1984). He is most known for his “EXCLUSION PRINCIPLE” pertaining to electron orbit occupation. Additionally, he introduced two new quantum numbers in 1924: the MAGNETIC QUANTUM NUMBER (m_ℓ) and the spin quantum number (m_s). He is one of the pioneers in quantum PHYSICS and received the Nobel Prize for his work in 1945 (see Figure P.26).

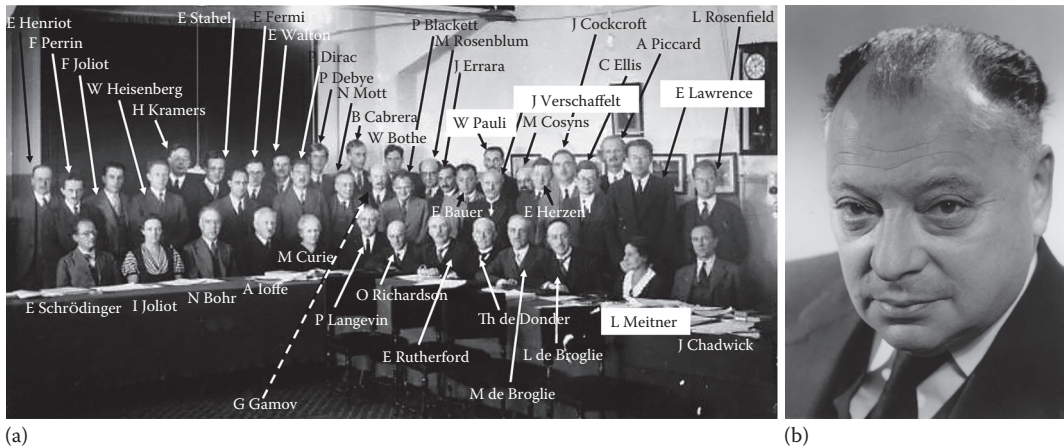


Figure P.26 (a) Wolfgang Ernst Pauli (1900–1958) at the 1933 Solvay Conference Structure et propriétés des noyaux atomiques: Structure and properties of the atomic nucleus; Chair Paul Langevin (1872–1946) (Courtesy of US Department of Energy (DOE) Washington, DC); (b) Wolfgang Pauli. (Courtesy of ETH-Bibliothek Zürich, Bildarchiv.)

Pauli exclusion principle

[atomic, nuclear] No two electrons in orbit in a single ATOM can exist in the same ENERGY and spin state. For instance, in helium the two electrons in the lowest energy state (with PRINCIPAL QUANTUM NUMBER $n = 1$) must have opposite SPIN states, with quantum numbers $\ell = 0$, $m_\ell = 0$ and $m_s = \pm(1/2)$. Electrons with the same principal quantum number will occupy the same “shell” (*also see* EXCLUSION PRINCIPLE).

Pauli spin matrix

[atomic, energy] Expression satisfying the commutator requirements describing the ELECTRON SPIN, represented as

$$\sigma_x = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}, \sigma_y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}, \text{ and } \sigma_z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}.$$

The commutator requirement expressions are based on the angular momentum expressions: $L_x = \hbar / i [y(\partial/\partial z) - z(\partial/\partial y)]$, where $\hbar = h/2\pi$ with PLANCK'S CONSTANT $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, and $L_y = \hbar / i [z(\partial/\partial x) - x(\partial/\partial z)]$, providing the commutators: $[L_x, L_y] = \hbar^2 [x(\partial/\partial y) - y(\partial/\partial x)] = i\hbar L_z$, $[L_y, L_z] = i\hbar L_x$, $[L_z, L_x] = i\hbar L_y$, and $[L_x, L_y] = i\hbar L_z$.

Paxillin

[biomedical, chemical, mechanics, signal] A 68 kDa neurofilament antibody cytoskeletal SIGNAL transduction adaptor protein involved in cellular organization as well as functioning of focal cellular adhesions. Paxillin adaptor proteins are critical in CELL ADHESION as well as in cellular migration.

PDT

[biomedical, chemical, optics] See PHOTODYNAMIC THERAPY.

Péclet, Jean Claude Eugène (1793–1857)

[energy, fluid dynamics] Physicist from France. He is most known for his contributions to FLUID dynamic definition and the PÉCLET NUMBER(S) (see Figure P.27).



Figure P.27 Jean Claude Eugène Péclet (1793–1857).

P

Péclet number (Pe)

[energy, fluid dynamics, thermodynamics] Dimensionless number used in HEAT TRANSFER representing the bulk heat transfer over the conductive heat transfer: $Pe = \nu L / \alpha = L \nu \rho c_p / \kappa = Re \times Pr$, with ν the velocity, L the characteristic length, α the thermal DIFFUSIVITY, κ the THERMAL CONDUCTIVITY, ρ density, c_p the heat capacity, Re the REYNOLDS NUMBER, and Pr the PRANDTL NUMBER. Generally used in forced convection and universal heat transfer. Named after the originator JEAN CLAUDE EUGÈNE PÉCLET (1793–1857).

Péclet number, mass transfer (Pe_m)

[energy, fluid dynamics, mechanics, thermodynamics] Dimensionless number used in mass transfer representing the bulk mass transport over DIFFUSIVITY of a constituent: $Pe_m = \nu L / D_{\text{dif}}$, with ν the velocity, L the characteristic length, α the thermal diffusivity, D_{dif} the DIFFUSION coefficient, based on the work of JEAN CLAUDE EUGÈNE PÉCLET (1793–1857). The mass transfer PÉCLET NUMBER is sometimes also referred to as the “SHEAR PÉCLET NUMBER,” specifically in SHEAR FLOW, such as in MICROFLUIDICS.

Peierls, Rudolf Ernst, Sir (1907–1995)

[acoustics, mechanics, solid-state] Scientist and physicist from Germany. His work on nuclear PHYSICS provided many theoretical insights, specifically treating the ATOM as having an electron cloud with discreet wavefunctions, different from the Schrödinger model (see [Figure P.28](#)).



Figure P.28 Rudolf Peierls (1907–1995), 1937 picture.

Peierls transition

[acoustics, mechanics, solid-state] Density WAVE in one-dimensional electron GAS. The ENERGY transfer takes place by exchanges between states, PARTICLE to particle transitions (Cooper channel), or particle to hole transitions (Peierls channel). The particle–hole transitions will exhibit periodic variations in charge density or SPIN density; as such these transitions are referred to as charge-density or spin-density wave GROUND states.

Peierls–Fröhlich–Kuper ground state

[acoustics, computational, mechanics, solid-state, thermodynamics] CHARGE DENSITY WAVE as a result of electron–phonon interaction in a partially filled electron band. Periodic lattice distortions create a single PARTICLE gap at the FERMI LEVEL. This transition forms an INSULATOR condition, known as the PEIERLS TRANSITION. The influence of an external electric field (nearby atoms or applied field creates a periodic instability as suggested by RUDOLF PEIERLS (1907–1995) in 1955, with theoretical support by Charles Goethe Kuper (twentieth century), and with independent contributions from HERBERT FRÖHLICH (1905–1991) in 1954 on a theoretical thermodynamic level. Under the particle gap migration, an electric current is generated on atomic level, specifically under the influence of an external electric field.

Peltier, Jean Charles Athanase (1785–1845)

[energy, thermodynamics] Physicist from France. He described the electrical potential resulting from placing two dissimilar materials in direct contact with each other—the PELTIER EFFECT (see [Figure P.29](#)).

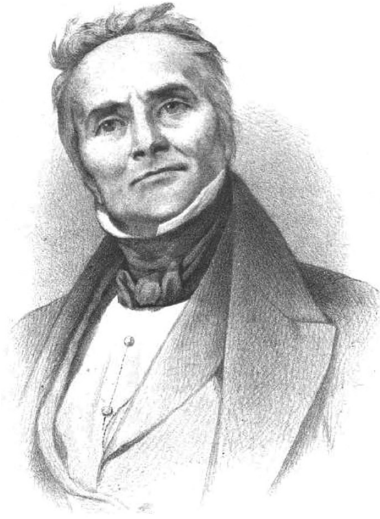


Figure P.29 Jean Charles Athanase Peltier (1785–1845).

Peltier coefficient

[energy, thermodynamics] Representation of the heat quantity transferred per unit charge for a specific material, placed in contact with another material ($\cdot$): Π . This concept relates to the PELTIER EFFECT.

Peltier effect

[energy, thermodynamics] Electrochemical effect, describing the thermoelectric principles involved in the thermocouple ACTIVITY of two metals joined together. The two metals will absorb heat at the METAL junction that is at a higher temperature and emit heat at the lower temperature junction. This was described by JEAN CHARLES ATHANASE PELTIER (1785–1845) in 1834. Respectively, when an electrical source is connected in the THERMOCOUPLE circuit in the inverse direction, heat will be generated at the high-temperature junction and heat will be absorbed (cooling effect) at the colder junction. The Peltier effect is generally associated with electric heating and cooling. One specific example is the electric heating stove-top. The scientific description is defined as the rate of heat generated or removed as a function of ELECTRIC CURRENT (I): $\dot{Q} = (\Pi_A - \Pi_B)I$, where Π_A , respectively, Π_B , are the PELTIER COEFFICIENTS for the respective conductors joined together. A similar principle was described earlier in 1826 by THOMAS JOHANN SEEBECK (1770–1831), but is primarily credited to Peltier (see [Figure P.30](#)).

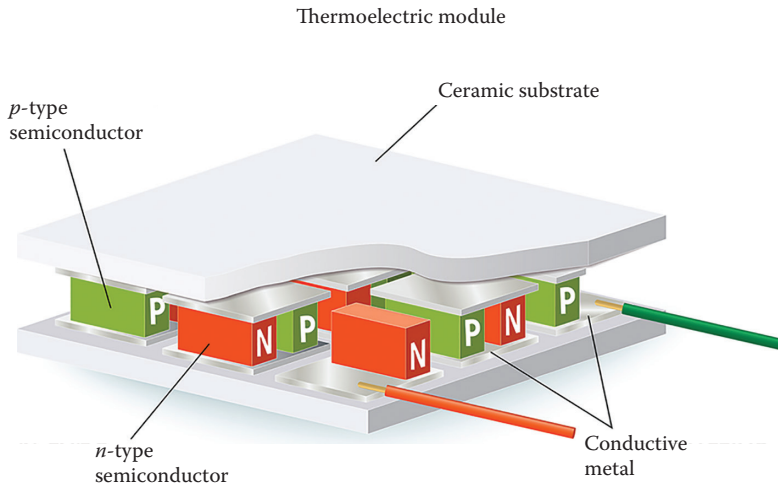


Figure P.30 Peltier element that cools based on the Peltier effect.

Pendulum

[general] Physical body that will rotate around a fixed axis when an external force is applied to initiate the removal from EQUILIBRIUM STATE; the device will produce a simple periodic MOTION. The first pendulum-based clock was constructed in 1657 by the scientist from the Netherlands: CHRISTIAN HUYGENS (1629–1695), who also developed the mathematical formulation for the pendulum. The pendulum will have a harmonic period (T) that is a function of the length from the axis of rotation to the center of mass (ℓ), the mass at the center of mass (m), the GRAVITATIONAL ACCELERATION (g), as well as the generalized MOMENT OF INERTIA (I_{inertia}), expressed as $T_{\text{period}} = 2\pi\sqrt{I_{\text{inertia}}/mg\ell}$. The pendulum, for small angular displacement ($\sin \theta \approx \theta$, where $\theta = A \sin(\omega t + \phi)$, with ϕ an arbitrary initial PHASE of motion (depending on the time of initiation of observation) and ω the ANGULAR VELOCITY, $\omega = \sqrt{g/\ell} = \sqrt{(mg\ell/I_{\text{inertia}})}$ as a function of time (t), without friction obeys the WAVE EQUATION ($\partial^2\theta/\partial t^2 + (g/\ell)\sin \theta = 0$). When considering that the pendulum experiences friction at the movement around the axis, the wave equation incorporates dampening as $I_{\text{inertia}}(\partial^2\theta/\partial t^2) + mg\ell\theta = \pm \tau_{\text{friction}}$, where τ_{friction} represents the torque resulting from the rotational friction with respect to the center of mass. The SOLUTION then yields a dampened angular swing, with decreasing displacement: $\theta(t) = [\theta_0 - (4t\tau_{\text{friction}}/\omega_0^2 I_{\text{inertia}} T_{\text{period}})]$. When the pendulum is submerged in a viscous fluid, the wave equation incorporates dampening as $I_{\text{inertia}}(\partial^2\theta/\partial t^2) + b_{\text{visc}}(\partial\theta/\partial t) + mg\ell\theta = 0$, where b_{visc} represents the viscous friction with respect to the center of mass, with ensuing DAMPING term $b(\partial\theta/\partial t)$. The fluid-dampened OSCILLATION has the solution $\theta(t) = \theta_0 e^{-b_{\text{visc}}t/2I_{\text{inertia}}} \cos(\omega' t + \phi)$, where the oscillation period decreases, expressed as $\omega' = \sqrt{((mg\ell/I_{\text{inertia}}) - \{b_{\text{visc}}/2I_{\text{inertia}}\}^2)}$, and $\gamma_{\text{damp}} = b_{\text{visc}}/2I_{\text{inertia}}$ is the dampening constant. GALILEO GALILEI (1564–1642) also worked on the pendulum concept, dating back to 1582, but never constructed a clock mechanism, nor defined the rhythmic motion aspects. Generally, a pendulum

is driven by a weight mechanism to maintain motion. The FRICTION from liquids will result in a dampened motion, except for in VACUUM; however, the gear and sliding friction also reduce the ENERGY content (see [Figure P.31](#)).



Figure P.31 Pendulum of a clock, ensuring proper time keeping. Sometimes adjustments to the length of the pendulum of a clock are required for calibration purposes.

Penumbra

[biomedical, general, geophysics] PHASE in “shadow” pattern created by an OPAQUE object irradiated from behind. The source can be a PARTICLE source or emit ELECTROMAGNETIC RADIATION. The three phases recognized are umbra, penumbra, and antumbra. During a penumbra only a portion (edge) of an emission source is obscured by the object, casting a shadow resembling a finger-nail clipping, as seen during the onset of a total eclipse of the SUN or generally a partial eclipse. The umbra represents a total blackout of the source on a projected surface, or when observed straight on (*Note:* Not advisable during the observation of a solar eclipse, since when the Sun peaks back out the radiance can literally be blinding.) and the antumbra has LIGHT passing around the object. Note that for a POINT SOURCE, only the umbra is produced. In biomedical

applications, this applies to RADIATION THERAPY, where the penumbra represents the biological space in the periphery of the spot irradiation location, and is generally defined as the tissue volume receiving only a partial dose, between 80% and 20% of the therapeutically intended isodose (see [Figure P.32](#)).



Figure P.32 Lunar eclipse, penumbra.

Perception

[biomedical, chemical, mechanics, optical, theoretical] Parameter of sensation. A sensation is quantified and qualified by several attributes and parameters, also defined as dimensions. One “quality” of a sensation is the subjective value that provides a name. The clinical classification of the senses is as follows. Special senses are VISION, auditory, taste, olfactory (smell), and vestibular (balance, equilibrium, spatial orientation; located in the vestibular system of the INNER EAR). Other superficial or cutaneous senses are touch/pressure, warmth, cold (separate from warmth), and pain (most overstimuli can produce pain in any of the sensing neurons with sensor specialization). Deep sensations are muscle/tendon/joint and position, deep pressure, and deep pain. Visceral sensations served by the autonomic nervous system are hunger and nausea for instance and visceral pain. Senses can also be organized by “location.” Somatic (“body”) senses are for instance temperature, either warm or cold; touch pressure; pain, next to “deep sensibility.” Deep sensibility is an indication of the knowledge and awareness to the relative position of the extremities (arms/legs; i.e., “muscle sense”) and the perception of the direction of MOTION with eyes closed. Generally, a power function can be attached to the sensation that links the MAGNITUDE of the stimulus (S) to the psychological magnitude (M): $M = K_{\text{sens}} S^2$, where K_{sens} represents a “personal” factor (“sensitivity,” “numbness”). Sensors can also be classified by their function: chemoreceptor, mechanoreceptor, and optical sensor. The sensation is ultimately a function of the type of nerve-fiber/sensor combination that is stimulated, not the ENERGY of the stimulus itself. The magnitude of the stimulus of the sense is encoded in a binary frequency train, which is logarithmically linked to the strength of the excitation. The fine free nerve-ending in hairy SKIN as well as nerve-baskets around the

hair roots are serving a variety of sensations, ranging from touch, to warm and cold. Specialized sensors are constructed of encapsulated nerve-endings, with various configurations and designs for specific applications; RODS and CONES for the RETINA of the EYE for instance. The RESOLUTION of a sense is a function of the number of sensors per unit area (sensor density); the fingertips of a mammal can gauge submillimeter resolution, whereas the palm spans several millimeters. Another highly innervated area is the lips. Since the lips are close to the brain, and conversely fast conducting nerves (i.e., myelinated nerves) are formed only slowly after birth, the lips are the most direct link to the brain for babies, most likely the reason why they touch everything with their mouth since the fingertips are not fully developed. Generally, several neurons carry information from different locations to the same functional area in the brain. Under normal conditions the brain can identify exactly where the sensation originates (potentially imbedded in other types of encoding, possibly “PHASE ENCODING,” which for a binary system is different than for an analog system, for instance using a phase shift for a “marker” pulse segment), whereas under overstimulus (very strong stimulus) the sensation is “projected” to the most distal point on the perception branch (see [Figure P.33](#)).



Figure P.33 Cartoon representation for sensory perception. Hearing, smell, taste, and sight; not specifically included: touch; however the lips have the highest density of sensors, providing resolution of better than 0.05 mm.

Perceptron

[biomedical, computational] Computational algorithm used in machine learning. The algorithm is designed to detect a linear threshold for an event or data trend. The linear function in vector components can be represented as $a_1x_1 + a_2x_2 + \dots + a_ix_i + \dots + a_nx_n > 0$ and in vector format as $\vec{a}^1 \cdot \vec{x} > 0$, threshold at zero, where $\vec{a}^1$ is a unit length vector. In a sequence (S_{seq}) of data with potential mistakes (M_{mis}), the “margin” (γ_{marg}) in the mistakes for the perceptron algorithm is $\gamma_{\text{marg}} = \min_{x \in S_{\text{seq}}} |\vec{a}^1 \cdot \vec{x}| / \|\vec{x}\|$, with the number of mistakes in the order of $(1/\gamma_{\text{marg}})^2$. This is one of the early concepts in machine learning, introduced in the early 1960s.

Percolation

[chemical, computational, geophysics] In chemical applications percolation references the filtration system, while in computational theory this defines the interrelation of data clusters in a graph that are connected (“neighbors”). Additionally, in geology, percolation refers to the CIRCULATION of water and the inherent filtration of water through the soil of the mantle as well as permeable rocks. The percolated water seeps to groundwater storage (i.e., aquifer). One particular mathematical use of percolation refers to the probabilistic interactions during PHASE transitions. The phase transitions are outlined in graphical representation (e.g., PV-DIAGRAM) for a region in the medium; percolation can describe the PROBABILITY (p) that the “edges” of the segment are open to the neighboring vertices (faces and edges; intersection in geometric space). Image and SIGNAL percolation generally involves finite ELEMENT analysis (Monte Carlo simulation) (see [Figure P.34](#)).

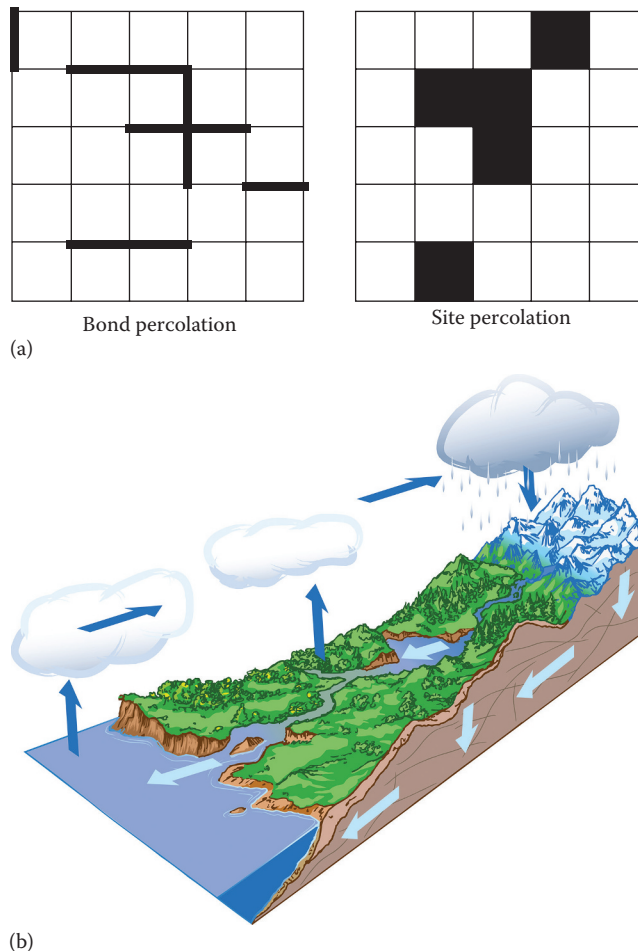


Figure P.34 (a) Image analysis percolation and (b) percolation of water in the atmospheric circulation and drainage to aquifer to be stored underground, ultimately with the opportunity to be used as drinking water due to the cleaning from the seepage.

Perfect diamagnetism

[general] Generally DIAMAGNETISM is the result of atomic current loop in response to an applied external MAGNETIC FIELD. The induced currents result in a magnetization within the diamagnetic material with a direction that opposes the applied field. When the external field is removed the magnetization disappears. The relationship between magnetization (M_{mag}) and the magnetic field (B) is expressed as a function of the volume MAGNETIC SUSCEPTIBILITY (χ_m) as $M_{\text{mag}} = \chi_m B$. In superconductor material, the magnetic field is zero and hence there will be no magnetization, that is, perfect diamagnetism (*also see* MEISSNER EFFECT *and* DIAMAGNETISM).

Perfect gas

[fluid dynamics, thermodynamics] An IDEAL GAS that has simplified stable equilibrium conditions (specifically behaving with a weak, dependence of the SPECIFIC HEAT on the temperature (in most cases negligible; i.e., $c_p = \text{constant}$ [constant pressure: P] and $c_v = \text{constant}$ [constant volume: V]), yielding $c_p - c_v = R$, where $R = 8.3144621(75) \text{ J/K mol}$ is the gas constant, and $c_p/c_v = \gamma_p$ a constant within a specific temperature range. The specific INTERNAL ENERGY of a perfect gas is defined as $U(T) - U_0 = (1/\gamma_p - 1)(PV - P_0V_0) = c_v(T - T_0)$, Δ_0 ; $V_0 = R(T_0/P_0)$ denoting the GROUND STATE or initial state. The specific enthalpy is defined by $h(T) - h_0 = [\gamma_p/(\gamma_p - 1)](PV - P_0V_0) = c_p(T - T_0)$. And finally the specific entropy as a function of combinations of respectively temperature, pressure, and volume: $S(T, P) - S_0 = c_p \ln(T/T_0) - R \ln(P/P_0)$, S_0 at P_0, T_0, V_0 (similarly for h_0 and U_0); $S(T, V) - S_0 = c_v \ln(V/V_0) + R \ln(P/P_0)$; $S(V, P) - S_0 = c_p \ln(V/V_0) - c_v \ln(P/P_0)$. Additionally, for the perfect gas along any ISENTROPIC the following holds: $TP^{-\gamma_p-1/\gamma_p} = \text{Constant}$; $TV^{\gamma_p-1} = \text{Konstant}$; and $PV^{\gamma_p} = \text{Konstant}$ (*also see* IDEAL GAS); however, the ideal gas is not necessarily equal to the perfect gas.

Perfect incompressible behavior

[fluid dynamics, geophysics, mechanics, thermodynamics] Poisson's ratio for incompressible media is $\nu_p = 0.5$. Incompressible VISCOELASTIC behavior has as boundary condition that the strain is finite. The MAGNITUDE of allowable finite strain is a function of the medium. Theoretically, media can have perfect incompressible behavior for several phases (solid, LIQUID, or gas). The equation of MOTION for perfect INCOMPRESSIBLE FLUID behavior assuming the absence of internal FRICTION was described by LEONARD EULER (1707–1783). Examples of materials that approach perfect incompressible behavior are several polymers: polystyrene, polycarbonate, polyvinyl acetate; as well as vulcanized natural rubber. Generally, the bulk modulus will decrease for a medium approaching $\nu_p \rightarrow 0.5$, and mathematically the ratio of bulk modulus to shear modulus will trend to infinity. Incompressible flow is described by the Euler equations.

Perfusion

[biomedical, fluid dynamics] Integral network of BLOOD vessels supplying nutrients and oxygen to bulk tissues and organs and removing waste and carbon dioxide. Vessels consisting of arteries, arterioles, capillaries, venules, and veins (see [Figure P.35](#)).

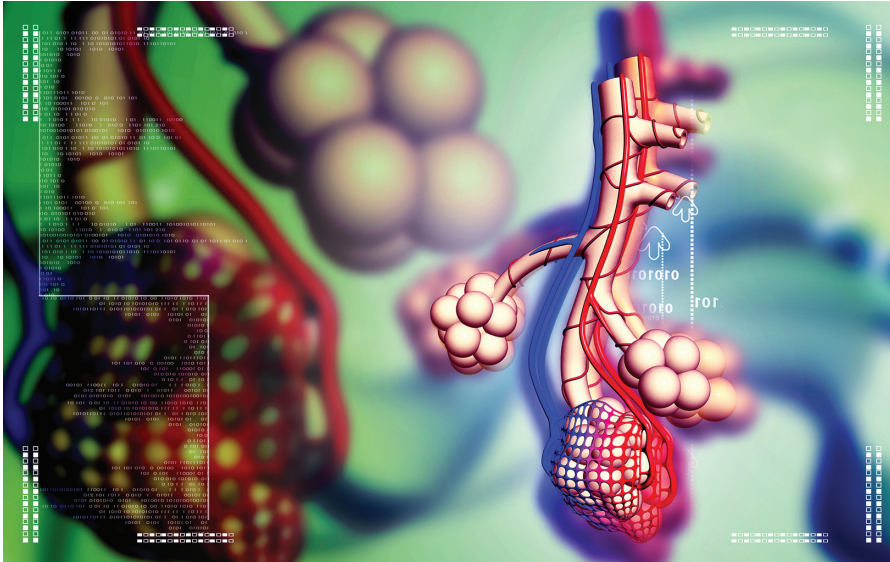


Figure P.35 Blood perfusion of lung tissue around the alveoli exchanging oxygen and carbon dioxide.

Pergrinus, Petri, a.k.a. Pierre de Maricourt (1220–1290)

[electromagnetism] Scientist from France, accredited with the first documented description of the use of the Earth's magnetism using a needle to map the MAGNETIC fields produced by magnetic objects as well as the Earth's MAGNETIC FIELD line patterns. Magnetic fields introduced by objects/particles and the Earth's magnetic field were known as far back as the thirteenth century before Christ. The work by Pergrinus postdates the early recording by almost 24 centuries (see [Figure P.36](#)).



Figure P.36 Plaque commemorating Petrus Peregrinus de Maricourt; a.k.a. Petri Pergrinus (1220–1290), a.k.a. Pierre de Maricourt.

Period doubling

[biomedical, computational] Sudden doubling of the frequency of a (PENDULUM) event. This may be graphically illustrated as a bifurcation in a POINCARÉ SECTION of an orbital plot in a QUALITY FACTOR versus ν -coordinate ($\nu = d\theta/dt$, where θ represents the angular path of a pendulum). In the statistical analysis of animal population as a function of time, on average the population will persistently gyrate between two values as a function of time with no consistent equilibrium. The rate of growth is a function of the fertility, which is a function of environmental and seasonal factors. Considering the dependence of an animal population as a function of its rate of growth will display a “bifurcation” for the population value as a function of growth. At a certain value of the rate, there is no established equilibrium in the population, and the number alternates between two values. This process of “bifurcation” continues, and the population will subsequently dissolve into chaos (see Figure P.37).

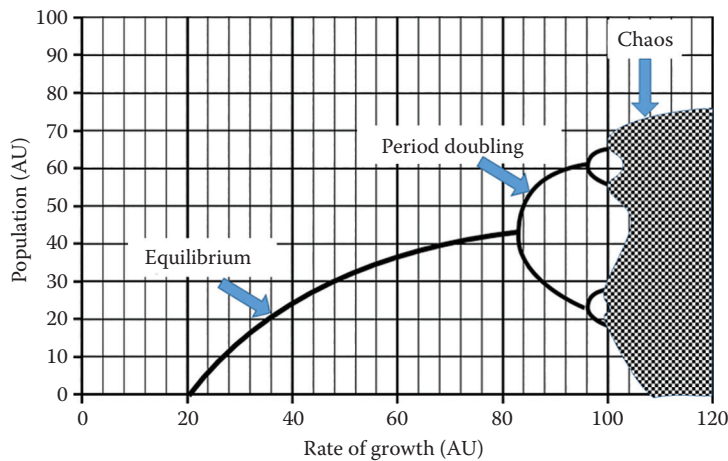


Figure P.37 Period doubling in population growth estimation based on graphical representation.

Period of a cycle (T)

[acoustics, general, mechanics, optics] The time frame (t) required to bring a period event back to a well-defined prior state (MAGNITUDE of displacement, field strength) with the same change of state configuration, primarily associated with a sinusoidal phenomenon such as a WAVE: $\mathcal{A} = \mathcal{A}_0 \sin[(t/T)2\pi]$ (see Figure P.38)



Figure P.38 Period, time to complete one sequence of events to the point where everything repeats itself, as in the revolution of a Ferris wheel, once around within a certain timespan.

Periodic law

[solid-state] Description of the perceived regular pattern in ATOM structural configuration with respect to electron structure as the basis for the PERIODIC TABLE OF ELEMENTS, introduced by DMITRI MENDELEEV (1834–1907).

Periodic table of elements

[atomic, nuclear] Discrete pattern of atomic configurations, nuclides, and electron orbits for the ELEMENTS as introduced by DMITRI MENDELEEV (1834–1907). The table designed by Dmitri Mendeleev listed the elements according to ATOMIC WEIGHT. In 1913 amateur theoretical physicist and economist Anton van den Broek (1870–1926) from the Netherlands suggested that the ordering principle for the periodic table should be based on ordinal numbers, i.e., the NUCLEAR CHARGE of each ATOM. This principle was validated by HENRY GWYN JEFFREYS MOSELEY (1887–1915) from Great Britain shortly thereafter, providing the final structure for the current use of the periodic table (see [Figure P.39](#)).

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Periodic waves

[general] Harmonic principle of ENERGY flow, where the MAGNITUDE of the representative phenomenon (e.g., mechanical deflection, electric or MAGNETIC FIELD strength, etc.) fluctuates with a fixed rhythm, indicated by the period of the WAVE (T), or the FREQUENCY ($\nu = 1/T$, expressed in Hertz [Hz]).

Periodogram

[acoustics, astronomy, computational, mechanics, optics] Periodogram is the statistical analysis of a time series of events that are not always periodic in nature. The events can be objects placed in a two-dimensional space (e.g. telephone poles) or sound AMPLITUDES, respectively light (ELECTROMAGNETIC RADIATION). One item of particular interest to the analysis by means of periodograms is in the occurrence of sunspots. Generally, a FOURIER TRANSFORM may not capture all the frequency data due to the unique and unevenly distributed nature of the events. The concept of the periodogram was introduced in the late 1800s. The periodogram concept can be in principle attributed to Sir Franz Arthur Friedrich Schuster (1851–1934), published in 1897. The periodogram analysis uses the discrete Fourier transform (DFT) as a basis, but requires several stages of averaging: *smoothing*. The periodogram uses the squared modulus of the DFT at selected frequencies, applied in asymptotic approximation. The FREQUENCY SPECTRUM analysis for the periodogram is primarily a statistical estimation process. It is the MAGNITUDE and span approximation for the spectral density of a periodic or discrete SIGNAL. A mathematical and statistical concept used to break down a complicated object of data stream, for instance a time series, into a sum of objects (e.g., spectral or temporal components) with reduced simplicity: $x(t) - \bar{x} = \sum_{k=2}^{(n/2)+1} \gamma_k \{a_k \cos[2\pi(t-1)\omega_k] + b_k \sin[2\pi(t-1)\omega_k]\}$, where ω_k represents the frequency components, $\gamma_k = 2$ unless $k = 1$, and a_k, b_k respectively the real and imaginary components of the Fourier transform of the data series. The individual components can then be studied separately. The less important components (low probability of impacting the overall outcome) can potentially be discarded to form a general approximation of the original phenomenon or object (also see FAST FOURIER TRANSFORM [FFT]) (see Figure P.40).

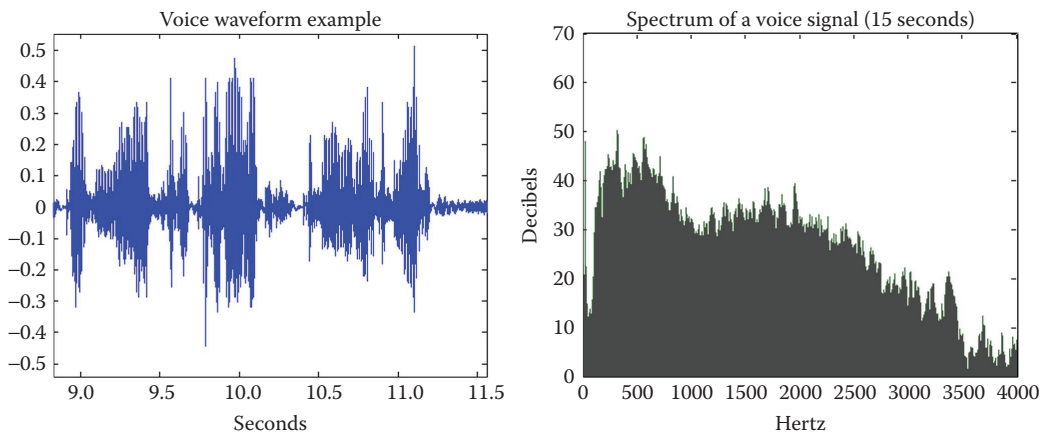


Figure P.40 Periodogram for the sound from voice over a time frame of 15 seconds, showing an amplitude graph for a section of 2.8 seconds only, with the calculated voice frequency on the right spectrum. Calculations performed by Matlab-MathWorks, Natick, MA, US. <http://www.mathworks.com/help/signal/ref/periodogram.html?requestedDomain=www.mathworks.com>. (Courtesy of National Center for Supercomputing Applications (NCSA) at the University of Illinois, Urbana, IL; Fortner Software, Unidata Program Center (netCDF), Boulder, CO; , The Independent JPEG Group (JPEG), Jean-loup Gailly and Mark Adler (gzip), and Digital Equipment Corporation (DEC), Maynard, MA.

Periphractic region

[fluid dynamics] Region in an irrotational segment of a moving FLUID, or electric respectively magnetic FLUX, which is defined by one or more closed surfaces. Also see **APERIPHRACTIC**, as found pertaining to Maxwell theory, where a closed surface may be contracted down to a point without losing the confinement for the region.

Peristaltic motion

[biomedical, mechanics] Sequential relaxation and subsequent contraction of circular muscles in antero-grade MOTION to form a WAVE-like propagation that mechanically transports the content within a biological tube, as found in the gastrointestinal track. The MUSCLE structure is smooth muscle. Certain worms also use this mechanism for in-line advancement on the exterior (see [Figure P.41](#)).

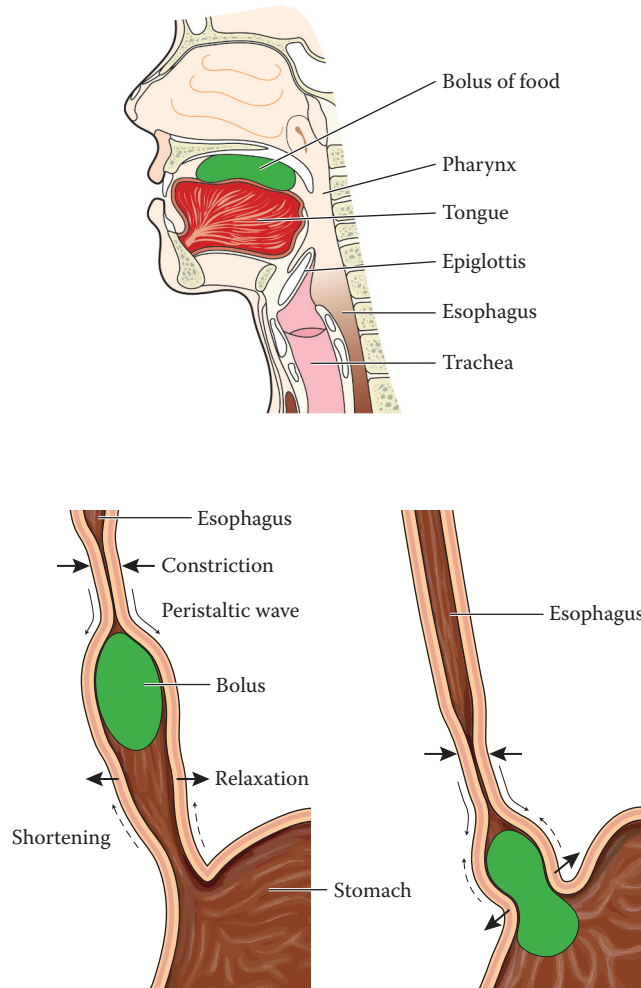


Figure P.41 The peristaltic motion of the esophagus as a result of swallowing food.

Perkins, Donald Hill (1925–)

[high-energy, nuclear] Physicist from Great Britain. He is best known for his contributions in PARTICLE physics, specifically the discovery of the negative PION in cosmic RADIATION (see [Figure P.42](#)).



Figure P.42 Donald Hill Perkins (1925–). (Courtesy of Physics Institute of the University of Bonn, Bonn, Germany.)

Permanent magnet

[general] See MAGNET.

Permeability (μ_{mag})

[biomedical, electromagnetism, energy, general, thermodynamics] $\mu_0^{\text{mag}} = 4\pi \times 10^{-7} \text{ H m}^{-1}$ for free space. Material property describing the ratio of the MAGNITUDE of magnetization (i.e., magnetic intensity) under the influence of a current through the material in a annular shape to the intensity of magnetization produced by the same current through a nonferromagnetic material with the same configuration of windings and dimensions. The permeability is an indication of the ability of the material to sustain the MAGNETIC FIELD. Generally, the permeability is a function of the magnetization itself, specifically for ferromagnetic media.

Permittivity (ϵ_{elec})

[biomedical, energy, general, thermodynamics] The electric field response of a medium under the influence of an applied external electric field. Measure of electric RESISTANCE of a medium under the process of forming an electric field within the medium. Note that the electric field is the electric potential per unit length resulting from separation of charges; how easily are the charges in a medium polarized under the influence of an external electric field. In a related definition, the electric susceptibility is an indication of the degree of POLARIZATION for a medium under the influence of an external electric field, the ease at which charges can be reorganized. The permittivity is the product of the RELATIVE PERMITTIVITY (ϵ_r) and the permittivity of free space ($\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2 / \text{N m}^2$).

Pérot, Jean-Baptiste Alfred (1863–1925)

[electronics, optics] Also PEROT French physicist most known for his work on interferometry with CHARLES FABRY (1867–1945). In spectroscopic analysis, the team developed the FABRY–PÉROT INTERFEROMETER (see [Figure P.43](#)).



Figure P.43 Jean-Baptiste Alfred Pérot (1863–1925).

Perpetual motion

[general] Any finite system by definition has finite INTERNAL ENERGY. In case a machine, or a system in general, performs work, energy is exchanged with the external system and the mechanism will have a decrease in internal energy by definition of CONSERVATION OF ENERGY (FIRST LAW OF THERMODYNAMICS). In case of perpetual motion, the system is supposedly crating more energy than it is producing allowing it to operate indefinitely without fuel (i.e., externally added energy). The system that operates for infinite period of time without contribution of external energy is referred to as the hypothetical case of perpetual motion of the first kind, which is theoretically and practically impossible. Perpetual motion of the second kind is claiming the possibility of extracting energy from the outside system without the requirements of a thermal gradient towards the system. This phenomenon would not violate the FIRST LAW OF THERMODYNAMICS; however, since it would supposedly effortlessly extract energy from the environment, this will violate the SECOND LAW OF THERMODYNAMICS, which prescribes a thermal gradient in order for heat to FLOW. The perpetual motion of the second kind presumably could extract energy against the gradient, that is, from a colder system, which is a practical and theoretical impossibility. The perpetual motion of the second kind however does not claim an infinite lifetime of operation, nor does it generate more energy than it consumes, but is still highly improbable and unrealistic (see [Figure P.44](#)).

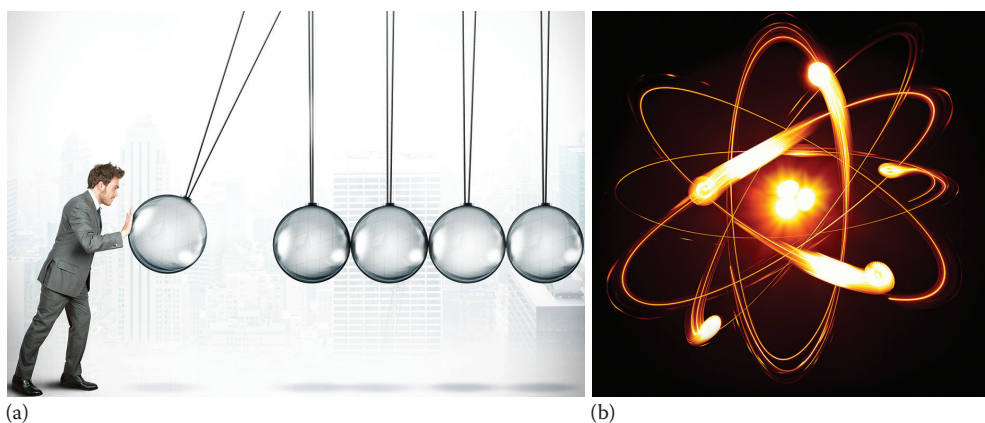


Figure P.44 (a) Apparent perpetual motion, the fact that a significant amount of energy was required to produce the “bouncing ball” device (i.e., Newton Cradle) and the fact that one ball needs to be pulled away initially by means of an external force by definition disqualify this device as a perpetual motion machine and (b) atomic motion is the closest system satisfying the perpetual motion theorem; still energy was added to this system during the primordial creation mechanism.

Perrin, Jean Baptiste (1870–1942)

[atomic, general, nuclear] Physicist from France who described the PHOTOELECTRIC EFFECT. Additional work by Perrin involved the BROWNIAN MOTION. He employed the description of Brownian motion provided by Einstein to derive the value of the Avogadro number. His work provided the following values for Avogadro's number $68.2 \times 10^{22} \text{ mol}^{-1}$ under the investigation of vertical velocity distribution; $68.8 \times 10^{22} \text{ mol}^{-1}$ for translational displacement; $65 \times 10^{22} \text{ mol}^{-1}$ under rotational DIFFUSION; and $69 \times 10^{22} \text{ mol}^{-1}$ under diffusion MEASUREMENT in the early 1900s, with respect to the established value (est. 2011; based on the work of LORENZO ROMANO AMEDEO CARLO AVOGADRO [1776–1856] in 1811) $N_a = 6.02213678 \times 10^{23} \text{ mol}^{-1}$. His work on CATHODE RAYS proved that their nature consisted of negatively charged particles. He also studied the effect on conductivity of gasses under the influence of X-RAY RADIATION. In addition, his work encompassed FLUORESCENCE, the disintegration of the radium isotope, next to the general phenomenon of emission and transmission of ACOUSTIC ENERGY (i.e., SOUND) (see Figure P.45).

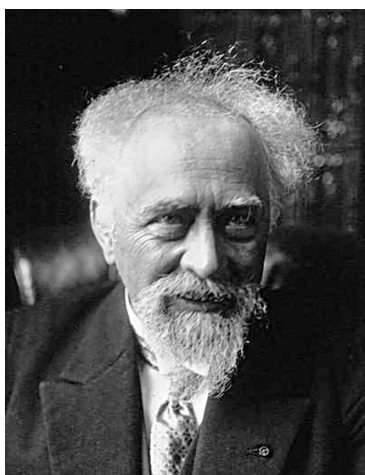


Figure P.45 Jean Baptiste Perrin (1870–1942).

Persistence time

[biomedical, computational, energy, general, mechanics] The average time frame between MOTION occurrences of significant influence relating CELL MOTILITY, for example, change in direction or MAGNITUDE: $\tau_{\text{persistence}} = \left\{ \theta_T (1 - \sin \phi) \right\}^{-1}$, where θ_T is the average time interval between two changes in direction and ϕ is the ANGLE between the prior direction and the new direction.

Perturbation theory

[atomic, computational] In wave MECHANICS the eigenfunctions of an applicable operator, such as the Hamiltonian ($H\Psi$), can be expanded in series. For certain cases, in atomic PHYSICS an exact NUMERICAL solution to the SCHRÖDINGER EQUATION may not be attainable. The case of perturbations in the Hamiltonian pertaining to fluctuations in the local potential can be difficult to ascertain. On a MACROSCOPIC scale, the same principles have been applied to the definition of PLANETARY ORBITS, first assumed to be circular, later found to be *approximating* elliptical tracks, due to various external influences. The process for the PLANETARY MOTION uses the following perturbation mechanism: first assume a single PLANET in an elliptical orbit, next add additional planets, and implement their influences (assuming that they also only move in an elliptical orbit; first perturbation). This allows the approximation of the velocity and the displacement of the planet. In the second-order approximation, the other planets will be calculated for their deviations on a recursive method, and the respective influence on the primary planet of interest. In the quantum-mechanical approach, generally the perturbations will proceed past the first order for initial investigations. The Hamiltonian can be enriched by a perturbing term (H' , perturbing Hamiltonian between quantum states): $H^* = H_0 + H'$, which is subsequently used in the Schrödinger equation: $H^* \Psi_k = E_k \Psi_k$, where E_k is the primary ENERGY distribution, and the solutions have the associated orthonormal eigenvalues (u_i). In first order, this yields only the direct influences, canceling out interactions between states $m \neq n$, at the perturbation $\square_m$: $\sum_{n=1}^{\infty} a_{kn} H'_{mn} = (E_k - E_{0m}) a_{km}$, where $H'_{mn} = \int u_m^* H' u_n d\tau$ is the matrix ELEMENT of the perturbing Hamiltonian H' between states m and k , with u_m^* the complex conjugate EIGENVALUE, $E_k = \sum_{n=1}^{\infty} a_{kn} u_n$, a_{kn} the EXPANSION coefficient (which are all zero except for a_{kk}), and $a_{km} \cong H'_{mk} / (E_{0k} - E_{0m})$ under the approximation $E_k \approx E_{0k}$. The simple example is for a square POTENTIAL WELL. A time-dependent version will apply to photon emission, gamma DECAY, beta and alpha emission as well as atomic and NUCLIDE collisions; this process involves a change of state, for instance from excited to GROUND STATE under photon emission. In this case, the state is defined as $\Psi = \psi_m e^{-(E_m/\hbar)t}$, with PLANCK'S CONSTANT $\hbar = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, which in this case will be required to satisfy the Schrödinger time-dependent equation: $H^* \Psi = i\hbar (\partial \Psi / \partial t)$, where $\hbar = h/2\pi$, and t denotes time. This provides a SOLUTION that yields the transition rate (λ_{trans}) from state ψ_m to all other states as $\lambda_{\text{trans}} = 2\pi/\hbar |H'_{km}|^2 (dN/dE)$, with N representing the accessible final states, and dN/dE the accessible final states per unit energy. The exact final state itself after transition can in general not be determined or experimentally derived. This last part is often referenced as “golden rule number two” (in the first-order perturbation approximation). The first-order probability of finding the system in state ψ_k is found to be $P_{\psi_k} = \left\{ (1/i\hbar) \int_0^t H'_{km} e^{-i\omega_{km}t} dt \right\}^2$, where $\omega_{km} \equiv (E_k - E_m)/\hbar$. (Note: “golden rule number one” applies to second-order perturbations, specifically where the matrix ELEMENTS H'_{km} will vanish under exchanges that do not violate the CONSERVATION LAWS.)

PET tracer

[biomedical, imaging] Radioisotopes that are used to TRACE specific metabolic or biological events in combination with POSITRON EMISSION TOMOGRAPHY (PET) imaging. For instance, ^{18}F —fluorodeoxyglucose has a half-life of 110 min, becomes part of the GLUCOSE, and is used to track tissue ACTIVITY (used in cancer research, neurology, and cardiology), ^{18}F —fluoride has a half-life of 110 min and is used in bone imaging, ^{11}C —PK11195 has a half-life of 20 min and is used for determining microglial activation, specifically associated with various neuroinflammatory and neurodegenerative diseases. Many more TRACERS are available to monitor physiological and anatomical features ranging from BLOOD flow, hypoxia, CELL binding studies, to dopamine receptor binding characteristics (e.g., drug efficacy), and cerebral ischemia as well as behavior studies based in viral infections (linking to the virus).

Peters, Bernard (1910–1993)

[atomic, geophysics, nuclear] Scientist from Poland (Prussia), contributor to the determination of the primary cosmic ray FLUX of nuclei with atomic number $Z \geq 2$, some in collaboration with Helmut L. Bradt (–1950). Peters and Bradt collected a significant amount of data during a balloon flight in 1948. This work provided essential information with regard to the ionizing potential with respect to the Earth's ATMOSPHERE (see [Figure P.46](#)).

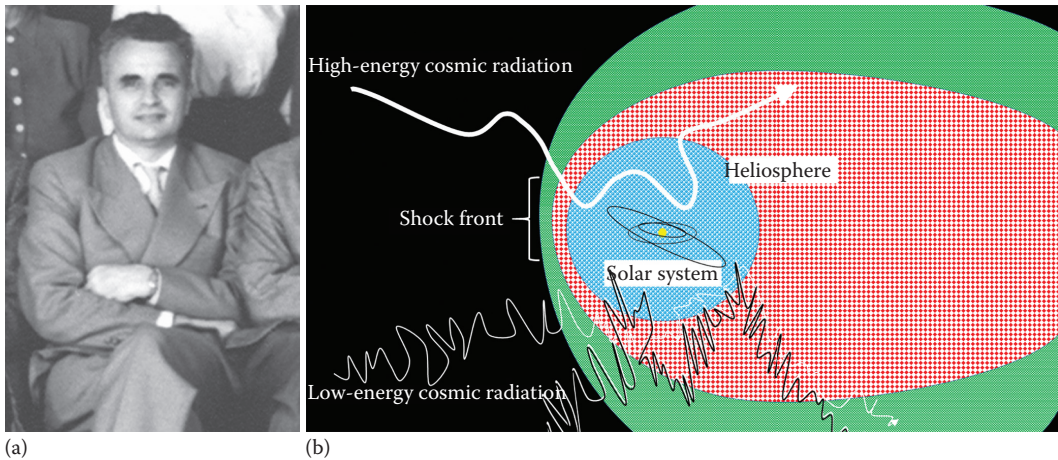


Figure P.46 (a) Bernard Peters (1910–1993) in 1959 (Courtesy of Niels Bohr Archive, Copenhagen, Denmark.) and (b) outline of atmospheric ionization based on the work of Bernard Peters.

Petit, Alexis Thérèse (1791–1820)

[thermodynamics] Physicist from France. His work provided significant insight into the efficiency of steam engines. Additional work was his discovery of the combustible nitrogen trichloride in 1813. Several efforts in his thermodynamic field were with PIERRE LOUIS DULONG (1785–1838) (see **LAW OF DULONG AND PETIT**) (see [Figure P.47](#)).

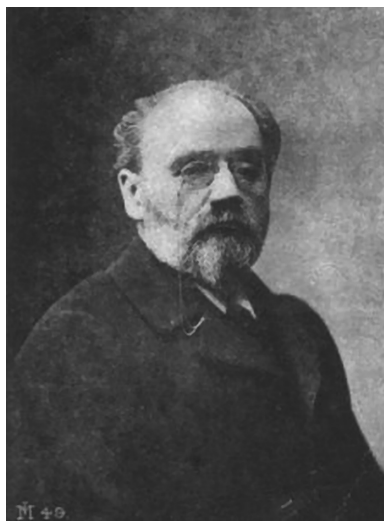


Figure P.47 Alexis Thérèse Petit (1791–1820).

Pfaff, Johann Friedrich (1765–1825)

[computational] Mathematician from Germany. His main focus was on special differential equations; specifically, he developed a method to solve series of complex interrelated functions, known as PFAFFIAN equations, which generally cannot be solved through normal mathematical mechanisms. One person particularly interest in Pfaff's work was JOHANN CARL FRIEDRICH GAUSS (GAUß) (1777–1855), pertaining to solving complex geometries for the derivation of the specific shape of MAGNETIC FIELD lines (see [Figure P.48](#)).



Figure P.48 Johann Friedrich Pfaff (1765–1825).

Pfaffian

[computational, thermodynamics] Differential equation with specific geometric configuration: $df = \sum_{i=1}^n X_i dx_i$, where the functions/phenomena X_i are dependent on individual or all the independent variables x_i . This equation is generally not considered to be a normal differential equation. The Pfaffian equation is for the specific condition: $df = \sum_{i=1}^n X_i dx_i = 0$. This process was developed by JOHAN PFAFF (1765–1825). These types of special differential equations often come into play in the field of axiomatic THERMODYNAMICS, based on the work of the German mathematician CONSTANTIN CARATHÉODORY (1873–1950) published in 1909, on an axiomatic approach to thermodynamics.

Pfund, August Herman (1879–1949)

[atomic, nuclear] Physicist and spectroscopist from the United States. Additional work by Pfund involved the invention and creation of a specialized spectroscopic TELESCOPE: the Pfund telescope. The mechanism of action of the Pfund telescope applies a method for realizing a fixed FOCAL POINT regardless of the

positioning of the line of sight of the telescope. Other work by Pfund was the creation of a special compass in 1944 in the investigation of POLARIZATION by the sky, called the Pfund sky compass (see [Figure P.49](#)).



Figure P.49 August Herman Pfund (1879–1949). (Courtesy of Johns Hopkins University, Baltimore, MD.)

Pfund series

[atomic, nuclear] Atomic transition LINE SPECTRUM for hydrogen described by AUGUST PFUND (1879–1949) in 1924. The observed ATOMIC EMISSION wavelengths (λ), respectively FREQUENCY (ν), were found to adhere to a very pragmatic equation. The paradigm is based on the BOHR ATOMIC MODEL transitions between electron orbits (n_i): $\nu = \left(m_e e^4 Z^2 / 8 \epsilon_0^2 h^3 \right) \left[\left(1/n_1^2 \right) - \left(1/n_2^2 \right) \right]$, for $n_1 = 5$, where $m_e = 9.10939 \times 10^{-31}$ kg is the electron mass, $e = 1.60217657 \times 10^{-19}$ C is the charge equivalence of an electron [–] (or respectively PROTON [+]), the permittivity of free space $\epsilon_{EM0} = 8.85419 \times 10^{-12}$ C²/N m², PLANCK'S CONSTANT $h = 6.62606957 \times 10^{-34}$ m² kg/s, Z the number of charges in the NUCLEUS, and n_2 the respective originating electron orbits (*also see PASCHEN SERIES* for additional detail) (see [Figure P.50](#)).

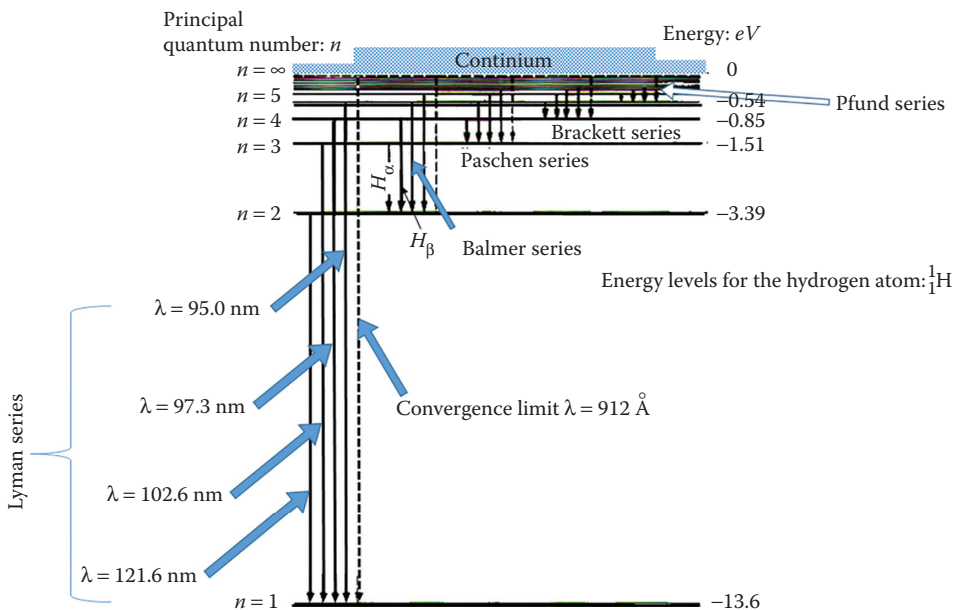


Figure P.50 Pfund series.

pH

[biomedical, chemical] Parameter defining the level of acidity or alkaline exchange of hydrogen ions (H^+) for a substance. A pH less than 7 generally indicates acidic and greater than or equal to 7 alkaline. The scale stretches from 0 to 14. pH is defined as the LOGARITHM of the hydrogen ion ACTIVITY (a_{H^+}) in SOLUTION: $pH = -\log_{10} a_{H^+}$, where the hydrogen ion activity represents $a_{H^+} = f^*[H^+]$, where f represents the activity coefficient, this describes the hydrogen ion mibility. The pH was originally defined by the Danish chemist SØREN SØRENSEN (1868–1939) based on the hydrogen ion concentration ($[H^+]$): $pH = -\log_{10} H^+$. The pH of certain liquids for instance ranges from; urine: $pH \rightarrow 6.5\text{--}7$ range; BLOOD: $pH = 7.38\text{--}7.42$ range.

pH VALUE	H ⁺ CONCENTRATION	
–1	Hydrochloric acid (found in the stomach for digestion); also known as muriatic acid	Acid
0	Battery acid	
1	Concentrated sulfuric acid	
2	Lemon juice, vinegar	
3	Orange juice, soda	
4	Tomato juice, acid rain	
4.5–6.5	Black coffee	
5	Bananas	
6	Urine, milk	
7	Pure water	Neutral
7.40 ± 0.05	Blood	Alkaline
8	Seawater, eggs	
9	Baking soda	
10	Great Salt Lake, milk of magnesia	
11	Ammonia solution	
12	Soap solution	
13	Bleach, oven cleaner	
14	Liquid drain cleaner	

The acidity of the blood plasma is tightly regulated between $pH = 7.38$ and 7.42 . The body's pH HOMEOSTASIS is essential to the proper progress of chemical reactions, survival of the cells, and ultimately survival of the organism. The pH is tightly monitored through chemoreceptors measuring the H^+ concentration in both the blood plasma and the cerebrospinal FLUID. Two organs of particular importance to tight control of acidity are the lungs and the kidneys. Central and peripheral pH sensors are located throughout the mammalian body, in particular in the internal and external carotid (neck, leading to the brain), the aortic arch (right after the egress from the left ventricle of the HEART), and in the medulla of the brain. Even though the blood–brain BARRIER provides poor permeability to H^+ , the acidity of the brain is influenced by means of carbon dioxide (cellular METABOLISM waste product): $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$, carbolic ACID. Note that the brain cells are perfused by an extracellular fluid (ECF) that is independent from the blood flow. The function of the chemoreceptors is to mitigate changes to the pH by influencing the RESPIRATION, through inducing the release of buffer solutions, and by means of KIDNEY function as a residual effort. Buffers are for instance $H_2PO_4^{2-}$ and HCO_3^- , which bind to H^+ and can be released from cells and ECF. In all these mechanisms contradictions can arise, for instance the increase of carbon dioxide (partial pressure of CO_2 ;

subsequent lower pH) subsequently decreases the binding of oxygen to hemoglobin. The latter results in the release of additional oxygen in regions that are rich in carbon dioxide, the BOHR EFFECT (see [Figure P.51](#)).



Figure P.51 Litmus paper used to indicate the acidity of a substance.

Phagocyte

[biomedical, mechanics] Specialized biological CELL that uses PHAGOCYTOSIS for the removal of extracellular material that may be considered harmful (see [Figure P.52](#)).

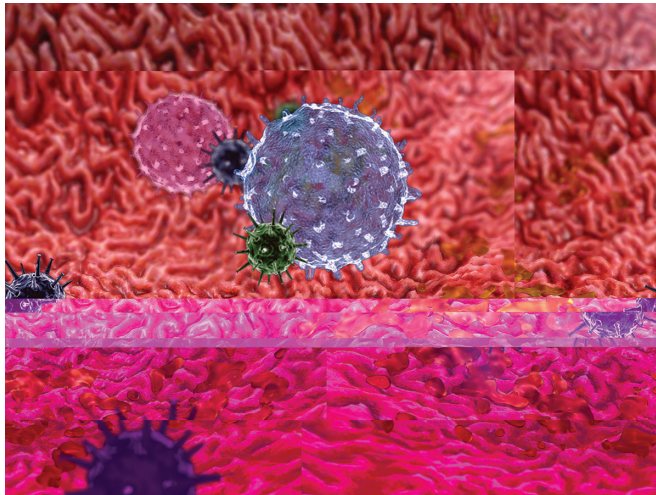


Figure P.52 Illustration of how a phagocyte captures the content of, for instance, medication (i.e., pill).

Phagocytosis

[biomedical, mechanics] The active mechanism for biological CELL to ingest solid items. The CELL MEMBRANE forms a vesicle that wraps around the material on the exterior of the cell membrane and subsequently transports the encapsulated material to the interior of the cell. The consumption process is part of the classification of ENDOCYTOSIS, which also includes consumption of LIQUID defined as PINOCYTOSIS. Generally, the PARTICLE size is larger than 1 μm . Specialized cells call phagocytes uses phagocytosis for the removal of pathogens. On the MECHANICS of the selective restructuring of the lipid-protein bilayer (*also see CELL MEMBRANE*) (see [Figure P.53](#)).

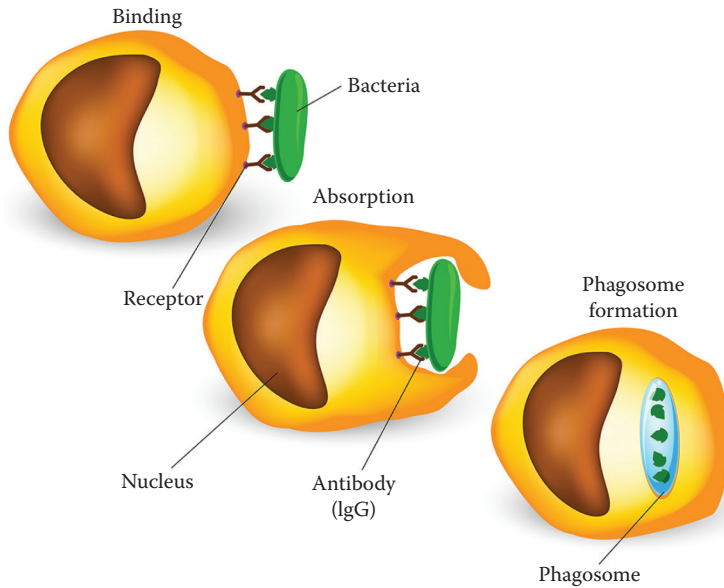


Figure P.53 The process of phagocytosis in biological cells. This is an active cellular deformation process. The local surface tension is adjusted actively to “open-up” the wall for consumption.

Phantom

[acoustics, computational, electromagnetism, optics] Artificially constructed medium that has most of the essential characteristics representative of the real object that needs to be investigated, specifically with respect to the ENERGY in question; ELECTROMAGNETIC RADIATION, particle beam, acoustic WAVE. For instance, a tissue phantom for PHOTODYNAMIC THERAPY dosimetry investigations can be constructed of a watery solution with SCATTERING particles (e.g., lipid [soy] or POLYMER [polyester; or other materials, including metals] of specific size; scatterer dimension determines both the scattering coefficient and the scattering anisotropy factor) and absorbing particles (e.g., Indian ink) (see [Figure P.54](#)).

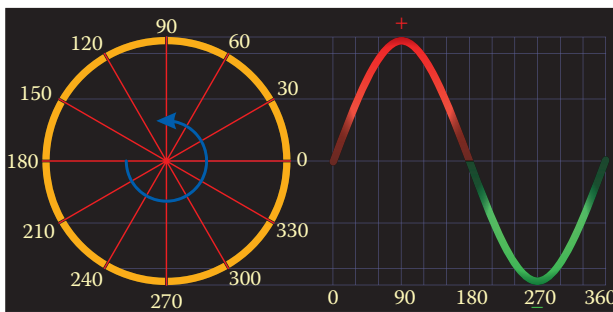


Figure P.54 The use of a phantom medium to illustrate the concept of a physics phenomenon, in this situation steam formation that is boiling water.

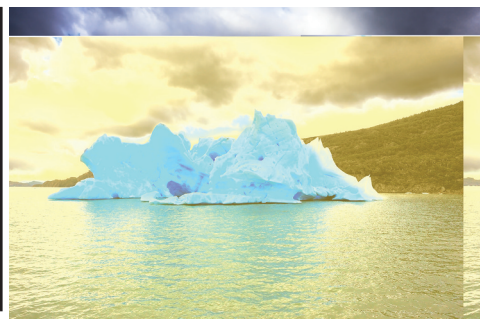
Phase

[acoustics, chemical, electromagnetism, fluid dynamics, general, geophysics, mechanics, quantum, solid-state, thermodynamics] Several particular definitions of phase are in use; geophysical phenomena, mechanics, material sciences, logistic processes, and thermodynamic processes. In material science and general PHYSICS, the phase indicates a location in a region of time and space, within which all physical characteristics of a medium, or a material, are fundamentally unvarying and uniform. In MECHANICS, the phase represents the angular fraction during a periodic process (e.g., sinusoidal) with respect to equilibrium at a chosen start time (i.e., the phase constant (ϕ) and the progression over time (ωt), pertaining to a rhythmic, HARMONIC MOTION: $\Phi = \Phi_0 \sin(\omega t + \phi)$, where $\omega = 2\pi\nu$ is the ANGULAR VELOCITY and $\nu = v/\lambda$ the frequency for a wave with wavelength λ under propagation velocity v . The frequency of the observation, WAVE, is of critical importance when comparing the respective phases. Two phenomena that are operating almost at the same frequency will experience INTERFERENCE at certain time frames when the respective wave crests match up, and this will generate a BEAT FREQUENCY of the combined phenomena. The beat frequency will be observable at the difference of the two frequencies: $\nu_{\text{beat}} = \nu_2 - \nu_1$, with respective AMPLITUDE $\mathcal{A}_R(t) = (\mathcal{A}_1 + \mathcal{A}_2) \cos\left\{2\pi\left[(\nu_2 - \nu_1)/2\right]t + \phi_i\right\}$; note that this only holds true for a deviation in the order of less than 0.25%, respectively less than 1 to several Hz, depending on several boundary conditions, including the MAGNITUDE of either wave phenomenon. A similar concept applies to the tuning fork used to tune a musical instrument. The phase of a wave phenomenon has a 360° or 2π recurrence, where 0 or 2π , respectively 360° , indicates complete in-phase, versus a phase difference between two events of 180° or π represents totally out-of-phase, or opposite phase. For waves the concept of superposition applies under all conditions.

Wave phenomena that are totally in-phase will provide a condition of **RESONANCE**, or amplification of the magnitude of the phenomenon, whereas totally out-of-phase characterizes cancellation. The phase difference is an indication how much difference there is in the “location” (in time and/or space, depending on the phenomenon or the specific **ENGINEERING** interests) of the respective crests of two waves of identical frequency. Generally, the phase of a wave will allow synchronization of events as well as imaging applications—coherence. Laser **LIGHT** by nature is coherent and hence in phase over the entire path of the emitted beam, extending over light-years. The phase of **ELECTROMAGNETIC RADIATION** is essential in the process of **OPTICAL COHERENCE TOMOGRAPHY** for instance. Other applications of phase related detection/sensing are based on the correlation between emitted and retrieved reflected waves in radar imaging of weather phenomena and objects in flight (e.g., airplanes), nondestructive testing (using electronic, optical, and acoustic mechanisms of action), **ULTRASOUND** imaging (**MEDICINE**), and radar detection of the velocity of an object, for instance used by law-enforcement agencies. In **ACOUSTICS**, the phase of a wave is predominantly determined by the dimension of the source, for instance a string on a cello or alternatively a **PIPE** organ. In **THERMODYNAMICS**, the phase represents the state of a medium: solid, **LIQUID**, gas, or plasma. In that regard, phase transitions refer to changes from liquid to **VAPOR** (vaporization) and solid to liquid (melting) and respectively for the reverse processes (condensation: vapor to liquid; **FREEZING**/congealing: liquid to solid), as well as solid to vapor (**SUBLIMATION**), and deposition: from gas to solid. Freezing is the phase change as a substance changes from a liquid to a solid. A **PHASE DIAGRAM** in thermodynamics illustrates the behavior of a medium as a function of pressure, temperature, and volume, specifically with respect to the exchange of heat. The **PHASE DIAGRAMS** usually illustrate the condition of a medium in a graph with the horizontal axis outlining the units of the independent variable considered in the study (abscissa, x -axis; Cartesian), either temperature or pressure, and the vertical axis the units of either the dependent variable in the study or in this case a second independent variable (ordinate, y -axis; Cartesian), the pressure. The angular phase of the process describes the stage in a distinct period of change or forming during the development of something; either a logistic course of action or a device design/manufacturing sequence of events. In a geophysical concept, the lunar phase describes the relative location of the **MOON** with respect to the **EARTH** under illumination by the **SUN** from a coordinate in space, providing a sequence of views of the Moon ranging from dark new moon to full disk full moon. The lunar phases range in appearance during eight key stages for its revolution around the Earth: new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, third quarter, and finally waning crescent (see [Figure P.55](#)).

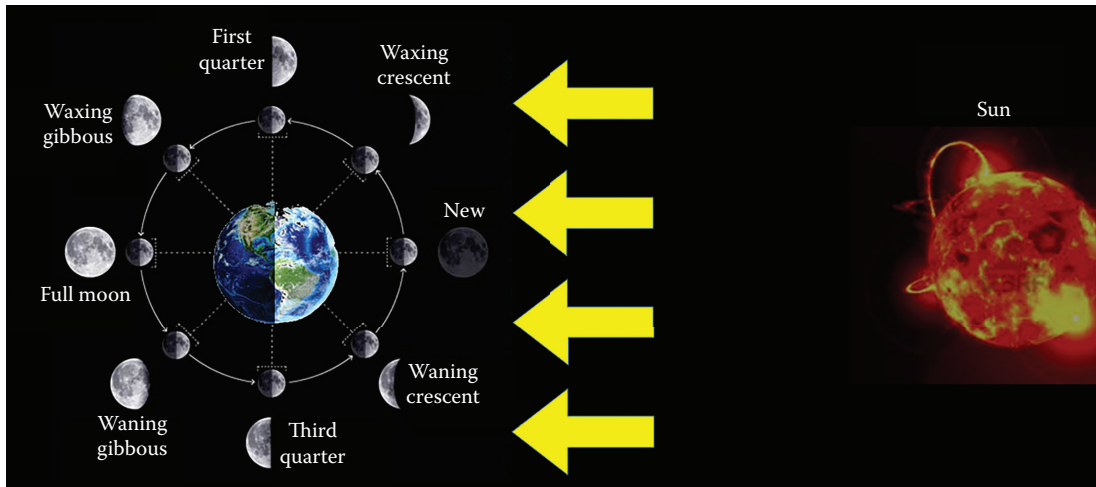


(a)



(b)

Figure P.55 Scientific use of the definition of phase (a) in wave formation and (b) in material characteristics liquid, solid, and gas. *(Continued)*



(c)

Figure P.55 (Continued) Scientific use of the definition of phase (c) in illumination stages for the Moon.

Phase cancellation

[acoustics, electromagnetism, fluid dynamics, general, mechanics, quantum, thermodynamics] The moment at which two periodic phenomena that operate at the same frequency are in opposite PHASE with each other and cancel each other out in its entirety (see [Figure P.56](#)).

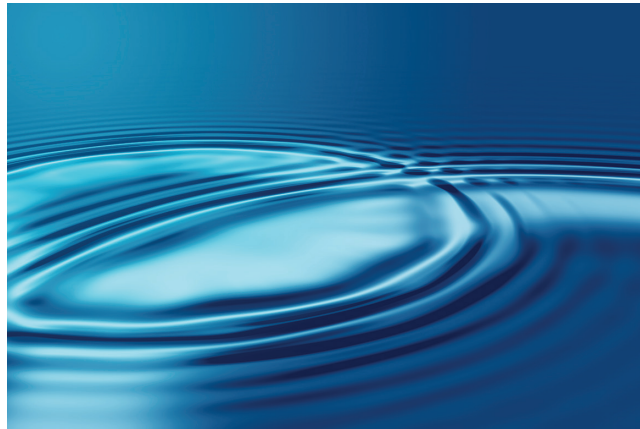


Figure P.56 Surface waves resulting from two perturbations in two different locations will result in merging waves where locations with opposing phase will cancel each other out yielding zero surface displacement.

Phase diagram

[chemical, computational, general, thermodynamics] Graphical representation of conditions used to illustrate at which point thermodynamically distinct phases can exist during equilibrium. The thermodynamic phase diagrams illustrate the phases of a medium under variable conditions of pressure, volume, and temperature, indicating the TRIPLE POINT (coexistence of LIQUID, VAPOR, and GAS phases at certain combination of pressure and temperature) and the critical point (the threshold temperature, when exceeded will result in a GAS PHASE for the medium regardless of the pressure) between vapor, liquid, and solid. More generally, the phase diagram illustrates the processes of FREEZING (SOLIDIFICATION)/melting, and vaporization/condensation,

while under certain circumstances the conditions for the formation of a plasma may also be included. Also referred to as PV-DIAGRAM, for pressure versus volume outline of the state of the medium, and as PT-DIAGRAM with respect to temperature (see Figure P.57).

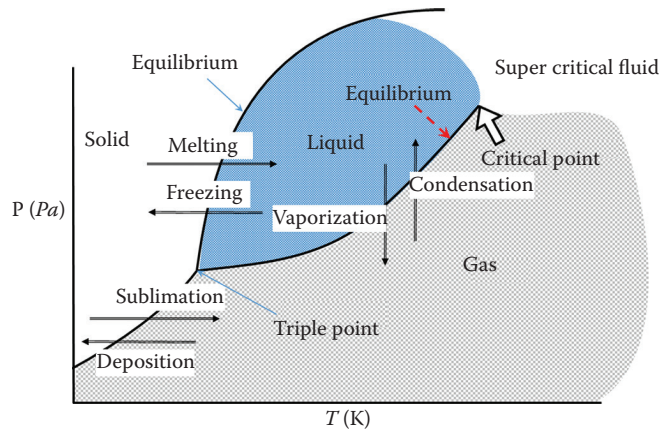


Figure P.57 Phase diagram.

Phase encoding

[biomedical, computational, theoretical] Signals that carry information can be encrypted with encoding mechanisms ranging from AMPLITUDE, phase to frequency, in both analog and digital SIGNAL transmission. The process of amplitude modulation is found in AM-RADIO, whereas frequency encoding is used in FM-radio and television to name a few. In order to create a greater discrimination and added security to avoid accidental “listening-in” or “hijacking” personal information, additional mechanism of encoding need to be implemented, including the highly configurable phase encoding. The phase encoding can be embedded with a preprogrammed phase DRIFT that is geared to the “receiver” conditions, such as that used in mobile phones. In imaging the process of phase encoding is for instance applied in magnetic resonance imaging (MRI), where the phase of a MAGNETIC FIELD is configured through altering the phase of spins in one dimension by pulsing the *magnetic field gradient* along the intended dimension of interest prior to the acquisition of the signal. The magnetic field has three components in a Cartesian system, where under imaging conditions the three respective vectors will have the same chemical frequency shift, and will subsequently possess the same Larmor frequency when exposed to a uniform magnetic field. If the applied gradient in the magnetic field is directed along the x -direction, the three magnetic field vectors will precess at a frequency given by the RESONANCE equation, with respect to the direction of the applied external magnetic field. On the other hand, the phase ANGLE (i.e., phase encoding) of each respective vector is not identical. The phase angle in this case represents the angle between a reference axis, either the x - or z -axis. Note that the magnetization vector will need to be discontinued at the time the phase encoding gradient takes place to avoid convolution of information. There are three distinct phase angles in this example. The subsequent spatial reconstruction can be explicitly and precisely located by means of FOURIER TRANSFORM analysis. The ensuing MRI spatial RESOLUTION is a direct function of the number of phase encoding levels applied to the respective field gradients. In telecommunications, specifically data transfer and data storage, phase encoding uses a clock frequency to provide a tuning mechanism for the collection of the signal. One other application is also found in card-key reader and access code using RFID (radio-frequency identification). Phase encoding on a digital basis uses a line code that has no DC-components, in which the encoding can be identified by means of ensuring that each data bit has at least one transition that occupies the same time. The clock signal can in this manner be recovered from the encoded data. Phase encoding is also used in 10BASE-T Ethernet (IEEE 802.3 standard). Digital phase encoding can apply highly configured phase trains, with a phase pattern repeater for imbedding many different sources of information. Temporal phase encryption disqualifies the coherent addition of various pulses in the frequency domain. This in itself

provides a platform for reducing the signal power spectral density. Hence eliminating the need to transmit the signal within the bandwidth used by the handler in order to conceal information within the signal spectrally. Spectral phase encoding provides a mechanism for temporal spreading of the pulse sequence, resulting in a stealth-like temporal and spectral transmission. This process applied for instance to optical communications by means of fiber-optics. On a biomedical level, phase encoding is potentially used to indicate the location of the source of a signal transmitted through the nerves, nervous system and identified by the brain (phase encoding for a binary system is different than for an analog system, for instance using a phase shift for a “marker” pulse segment). Further decoding is with respect to the digitally encoded characteristics of the observation, such as COLOR, taste, etc., MAGNITUDE as well as the physical characteristic itself (touch versus pain, brightness versus pin/threat, etc.) where the encoding will first allow only the appropriate receptor (brain function segment, special dedicated functional areas in the brain for sensation, MOTION control and thought, in addition to lobes for “mood/character”) to collect the relevant data. The intensity/magnitude of any sensation is represented in the frequency aspect of the binary signal; higher frequency pulse train indicates stronger sensation. For instance, the EYE has three CONES for RED, green, and blue, but the communication process through many branches and matrices of nerve cells, synaptic junctions, and amplifier stations (one nerve exciting multiple downstream nerves) does provide an accurate PERCEPTION after an elaborate signal processing network. Furthermore, after damage to the nerve system, respectively the brain, under certain conditions other nerve paths and respective brain segment can “learn” to acquire the data and encode it, which may initially be flawed but can grow to a highly accurate representation varying per individual since biology is by far not an exact science and has a wide range of boundary conditions that influence the final outcome. Respectively, sometimes the biological encoding may not be intact or “perfect” by nature, for instance resulting in reduced perception or “signal confusion,” such as certain forms of colorblindness or the often learned behavior for flavor (e.g., dislikes, thresholds). Phase encoding is also known as Manchester encoding, developed by the University of Manchester, Manchester, United Kingdom (see Figure P.58).

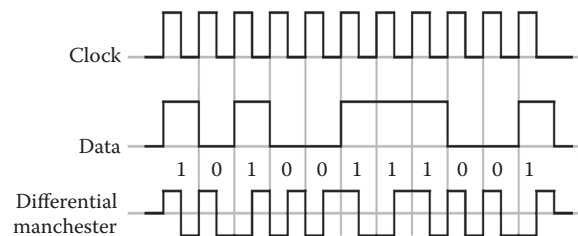


Figure P.58 Conceptual representation of phase encoding.

Phase noise

[acoustics, electromagnetism, mechanics] Noise in general is SIGNAL that deviates from a well-defined spectral and AMPLITUDE configuration. Noise can be generated as the result of the phenomenon itself, creating harmonics and specifically harmonics that are not in sync with the primary WAVE, or have fluctuating amplitude for the respective orders as a function of time. Other sources of NOISE originate from the medium in which a signal is generated or through which it will travel, providing DISPERSION next to dampening effects, with different MAGNITUDE for different frequencies and spatially diverse. Specifically, crystals produce inherent noise due to the source properties pertaining to freedom of movement of the oscillator; mechanical constraints will automatically induce harmonics and dispersion effects. Thermal effects also provide a main cause for noise, due to collision interactions. Since noise contains components at multiple frequencies, the respective phases will have a random distribution, as well as the amplitudes will be randomly distributed over time and spectrally. Noise is described in statistical terms because its magnitude is constantly and randomly changing. However, one can assign an average amplitude (A) that can be expressed in root-mean-square (RMS) value. Phase noise has implication in both the FREQUENCY (ν) and TIME (t) domain. In particular, in the time domain it causes jitter in the acquired signal. In the frequency

domain, the phase noise contributes to a PHASE shift (ϕ_{random}): $A = \{A_0 + A_{\text{noise}}(t)\} \sin(2\pi\nu_0 t + \phi_{\text{random}})$. The signal will appear as a primary component with sidebands (*also see NOISE*) (see [Figure P.59](#)).

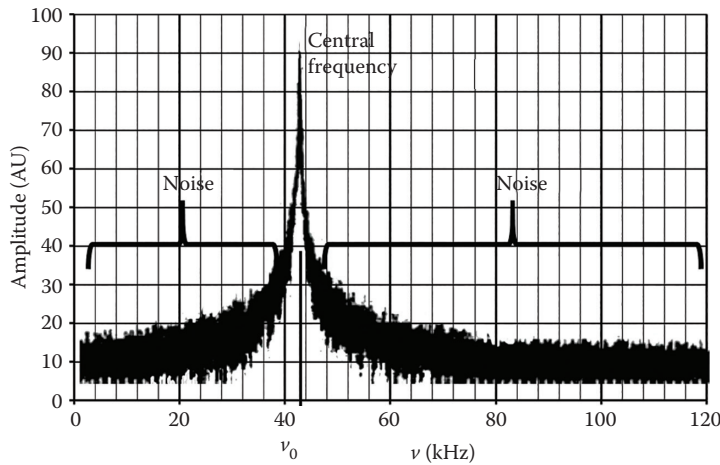


Figure P.59 Graphical representation of the phase noise spectral profile.

Phase rotation

[acoustics, computational, mechanics, theoretical, thermodynamics] In a polyphase system, the order of waveform sequences. In electrical applications, the power supply will have a specific PHASE associated with the alternating current ($I_i = I_{i,0} \sin(\omega t + \phi)$). In a three-phase system (high-voltage, high-power consumption electric motor design, e.g., crane), the three power supplies will have their own respective phases that will interact with each other inside the electric motor, allowing the MOTOR to rotate one way and when switching two of the phases it will reverse the direction. Operational process for three-phase alternator: PHASE SEQUENCE for proper operations; clockwise: Also described as phase “sequence.” Alternatively, in acoustic communications with one TRANSDUCER and multiple receivers, the collected phase at the respective receivers can be subject to DOPPLER shift or DISPERSION, creating a SIGNAL processing complexity due to the various signal phases related to the information transmitted for the single source, specifically pertaining to imaging (communications, scanner array). In particular, the use of a PHASED ARRAY in ULTRASOUND imaging relies on phase rotation to systematically build a three-dimensional IMAGE (see [Figure P.60](#)).

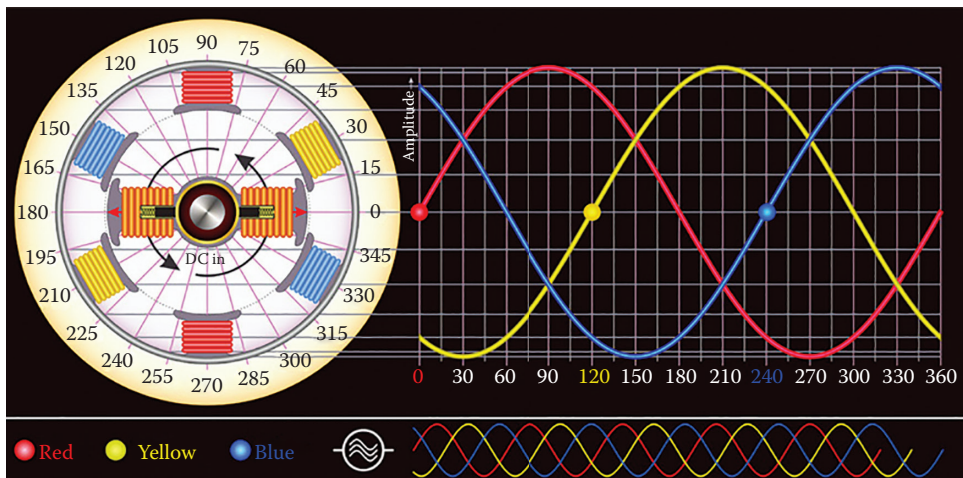


Figure P.60 Phase rotation for a three-phase generator, Crane using a three-phase electromotor.

Phase rule

[thermodynamics] Mechanism to determine the MAGNITUDE of the number of DEGREES OF FREEDOM (DF), respectively the variance of a chemical system, proposed by JOSIAH WILLARD GIBBS (1839–1903) in 1875: $DF = 2 + C_n + P_{\text{chem}}$, with C_n the number of constituents in the chemical mixture and P_{chem} the respective number of phases present within the system. The PHASE is defined as the part of a system that is chemically and physically homogeneous. The region confined to certain phase is bounded by a distinct interface with respect to other phases and can be physically separated from other phases. The phase rule defines the possible number of equilibrium situations for a system or chemical reaction. The phase rule has particular application in PHASE DIAGRAMS. For instance at triple points, all phases must coexist in the adjacent stability fields as well as at equilibrium lines (see Figure P.61).

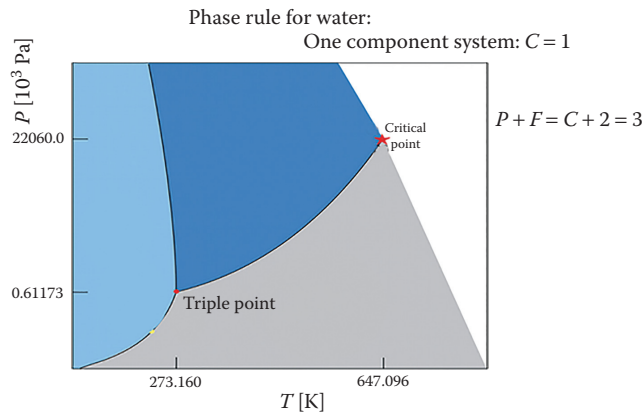


Figure P.61 Graphical representation of the phase rule principles.

Phase sequence

[acoustics, computational, mechanics, thermodynamics] See PHASE ROTATION.

Phase space

[atomic, computational, nuclear] A graphical statistical representation space in which all possible physical and thermodynamic states of a system are outlined. Each possible state of the system in the phase space will have an assigned unique point. One example is the representation of location and respective momentum ($p = mv$, with the mass m at location x , traveling at velocity v) for all coordinates of the constituents of a system. The Hamilton operator (H) connects the location to the momentum, which can be observed dynamically, creating what can be considered a Hamiltonian flow in phase space. The VOLUME (V) in this phase space ($dV = dp_x dx$) is conserved: $(1/V)(dV/dt) = \nabla \cdot f(\eta_{\text{phase}}) = \partial/\partial x (\partial H/\partial p_x) + (\partial/\partial p_x)(-\partial H/\partial x) = 0$, where $\eta_{\text{phase}} = (x, p_x)$ represent the location (phase point) in phase space, and $\partial \eta_{\text{phase}}/\partial t = f(\eta_{\text{phase}}) = [\partial H/\partial p_x, \text{ and } -(\partial H/\partial x)]$ is known as the Liouville theorem. The mathematical concept of phase space was unknowingly introduced by the French mathematician JOSEPH LIOUVILLE (1809–1882) in 1838. Liouville's work was further refined

approximately in 1842 by the German mathematician CARL GUSTAV JACOB JACOBI (1804–1851), without a direct reference to space or phase, but with a consistent and working mathematical treatment. Additional work by LUDWIG EDUARD BOLTZMANN (1844–1906) in 1866 also references the concept of phase space with respect to his theory of gasses, introducing a new field of statistical MECHANICS (see Figure P.62).

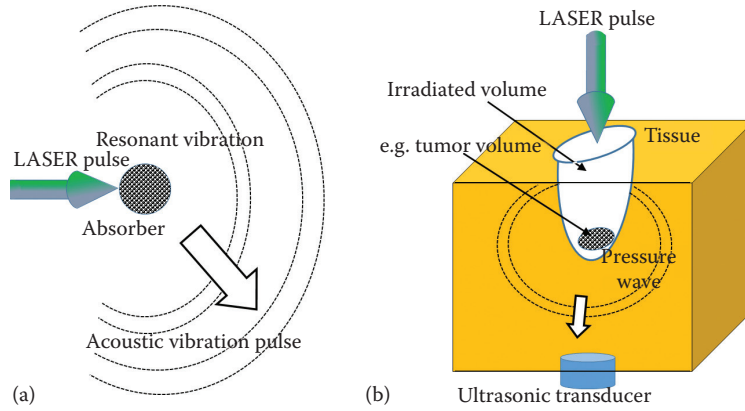


Figure P.62 (a,b) Phase space for electroencephalogram (EEG) monitoring. Courtesy of Michel Le Van Quyen.

Phase transition

[computational, thermodynamics] Conversion between the three states of solid, LIQUID, and gas. The following phase transitions are recognized: liquid to VAPOR: vaporization; vapor to liquid: condensation; solid to liquid: melting; liquid to solid: FREEZING/congealing; solid to vapor: SUBLIMATION, and gas to solid: deposition. Additional PHASE transitions are recognized as conducting-to-superconducting, fluid-to-superfluid, as well as solid-to-solid transitions. With any phase transition, a LATENT HEAT is associated defining the total heat (Q) required to transform a mass (m); for instance for solid to liquid or vice versa the latent heat of FUSION L_f , providing $Q_f = mL_f$, respectively for vaporization L_v . Note that all these transitions are reversible. Two phases of the same single-component system in equilibrium have equal Gibbs free ENERGY ($G = H - TS$, where H represents the system enthalpy, T the temperature, and S the entropy). Phase transitions are categorized by the Ehrenfest classification. The order of the phase transition is defined based on the order of the lowest order derivative at the phase boundary involved in the transition, which changes discontinuously (*also see* SECOND-ORDER PHASE TRANSITION).

ORDER	GIBBS DIFFERENTIAL		CORRESPONDING CHARACTERISTICS		
First	S	V	S	V	
Second	$(\partial S/\partial T)_p$	$(\partial V/\partial T)_p$	c_p	β	K_p
	$(\partial S/\partial P)_T$	$(\partial V/\partial P)_T$			
Third	$(\partial^2 S/\partial T^2)_p$	$(\partial^2 V/\partial T^2)_p$	$(\partial c_p/\partial T)_p$ $(\partial c_p/\partial P)_T$	$(\partial \beta/\partial T)_p$ $(\partial \beta/\partial P)_T$	$(\partial K_p/\partial T)_p$ $(\partial K_p/\partial P)_T$
	$\partial^2 S/\partial T \partial P$	$\partial^2 V/\partial T \partial P$			
	$(\partial^2 S/\partial P^2)_T$	$(\partial^2 V/\partial P^2)_T$			
S , Entropy	P , Pressure	V , Volume	c_p , specific heat under constant pressure	$\beta = 1/\kappa_b T$ $\kappa_b = 1.3806488 \times 10^{-23}$ $\text{m}^2 \text{kg/s}^2 \text{K}$, the Boltzmann constant	K_p , equilibrium constant: $\ln(K_p(T))$ $= -(1/RT) \sum v_i \mu_i^0(T)$; $R = 8.3144621(75) \text{ J/K mol}$ The gas constant; v_i the stoichiometric coefficient $\mu_i^0(T)$ the chemical potential for component $\square_i$

Phase velocity

[acoustics, atomic, mechanics, nuclear, optics] Speed at which any fixed PHASE of the cycle of a WAVE is displaced: $v_p = \omega/\kappa = \lambda v$, where $\omega = 2\pi v$ is the ANGULAR VELOCITY of a single wave form operating at frequency v , $\kappa = 2\pi/\lambda$ the wavenumber, and λ the associated wavelength. This stands in comparison to “group velocity” and “wave velocity.” For a composite waveform, the individual frequencies will experience DISPERSION, causing deformation in the wave pattern.

Phase-locked loop

[electromagnetism, theoretical] A closed-loop phase-based frequency control feedback mechanism, locking in on the primary WAVE. The phase-locked loop (PLL) is an electronic circuit designed for PHASE sensitive detection, for instance in communication (e.g., RADIO), of electrical phase difference between the received input signals and the output signals of a tunable oscillator. The tuning mechanism relies on continuously adjusting the oscillator frequency of the receiver tuner to match the phase of the frequency of the input SIGNAL, hence reconstituting the acquired signal with reduced NOISE. In communications, the PLL modulates and respectively demodulates the collected signal to provide uninterrupted reception with few distortions (breaks in communication) and low noise. The PLL can be voltage controlled or current driven, using the CARRIER frequency of the source as the control mechanism for accurately matching up the receiver signal. The tuning oscillator (e.g., crystal-controlled reference oscillator; voltage controlled oscillator: VCO) is approximately tuned to the intended frequency by means of component value selection (e.g., RC value for

recovery time). With the help of a phase comparator circuit the receiver seeks out the frequency and will lock onto the desired frequency. The phase detector produces a voltage that is proportional to the phase difference between the input and reference signal, where it is used to provide a reduction in difference feedback in the loop filter. In radio reception, this principle is achieved by the DEMODULATOR (FM-radio). The combination of PLL, VCO, reference oscillator, and phase comparator (phase detector that compares the phase of the signal derived from the oscillator to the input signal) forms what is called a frequency synthesizer.

Phase-only imaging

[acoustics, imaging, optics] Imaging technique based on using only the PHASE information of the AMPLITUDE in a complex formation of a WAVE. One specific application of phase-only imaging is applied to HOLOGRAPHY. Phase-only imaging has a reduced bit rate over conventional imaging and requires less data storage. It will still provide high-resolution images.

Phased array

[acoustics, biomedical, computational, electronics, geophysics, imaging] Source (e.g., piezoactuator and ANTENNA) composed of a multitude of radiating ELEMENTS each equipped with a PHASE shifter to provide a predetermined phase difference between respective, individually wired, elements. The consecutive phase shift between elements can turn the direction of a plane wave without physically changing the location of the emitters, and provide a focusing mechanism: BEAM FORMING. The beam steering ANGLE (θ_s) is directly based on the phase difference ($\Delta\phi$), the intersource spacing (d), and the source wavelength (λ): $\Delta\phi = 2\pi(\sin \theta_s / \lambda)d$. When performing a scan, a sweep may be performed by changing the phase according to $\exp[i2\pi(\sin \theta_s / \lambda)d]$. The detection mechanism uses the original phase difference to exclude detection from other respective sources, and additionally relies on INTERFERENCE for contrast enhancement. In ULTRASONIC IMAGING (nondestructive testing, medical imaging), this device operation can be used in sweep mode, where the phase angle is altered in a predetermined pattern to perform a sector scan. The sweeps are performed at high frequency (kHz). Because of the inherent semi empirical approach the decoding will require a look-up table for IMAGE reconstruction (see Figure P.63).

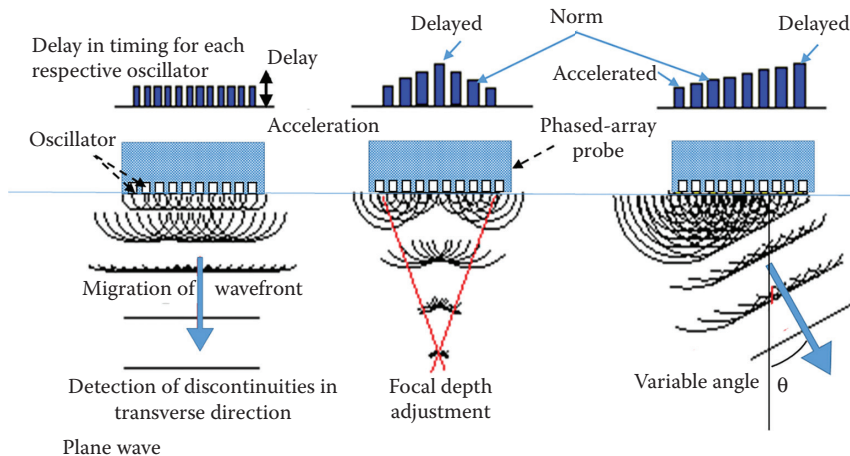


Figure P.63 Diagram of phased array, such as those used in ultrasonic imaging.

Phasor

[atomic, computational, general] Graphical representation of two quantities that are linked by a time-dependent relationship (e.g., alternating, harmonic), potentially resulting in a delay in PHASE between the two oscillatory phenomena (e.g., current in an electronic circuit versus voltage; presented as a function of the phase ANGLE between the two). Alternatively, the depiction of a rotating vector from a sinusoidal phenomenon as a function of ANGULAR VELOCITY (ω) with AMPLITUDE A . A phase vector. Also described as the Smith chart in electronic design.

Phosphorescence

[atomic, optics, solid-state] The ability of a substance to semi autonomously emit light (photoluminescence), without the requirement of excitation by ELECTROMAGNETIC RADIATION as under FLUORESCENCE. Phosphorescence may be fueled by chemical processes. During biological emission of light, such as that found in bacteria, squids, blooming phytoplankton, and certain fish, the pigment flavin, LUCIFERIN, is oxidized in the presence of an enzyme luciferase. The luciferase is also produced by the organism itself. One particularly well-known form of BIOLUMINESCENCE is found for the fire-fly. Phosphorescent substances have the ability to store up light and release it gradually. The notion of a metastable state explains this. If the molecules of the substance can get from the GROUND STATE to a metastable state, and if the metastable state can slowly DECAY back to the ground state via PHOTON emission, then we have phosphorescence. The mechanism of action of phosphorescence relies on the excited metastable triplet state, with respect to the ground state that is a SINGLET STATE. The TRIPLET STATE is defined for a MOLECULE containing two unpaired electrons that can migrate between three spin-states. Each of the electrons is subject to spin-orbit coupling; however, each with respective strengths s_1 and s_2 , which will subsequently precess at different rates. A SPIN triplet consists of a set of three QUANTUM states, each with respective total spin $S = 1$. The MAGNITUDE of the resultant spin vector, $s_1 + s_2$, will tip back and forth between quantum states $S = 0$ and $S = 1$. Hypothetically, the system could consist of just a solitary elementary “spin 1” PARTICLE, of undefined size. The active molecules can be raised from the ground state by ENERGY absorption (chemical, electrical, electromagnetic) to excited singlet states. Most frequently, they will immediately return to the ground state, emitting a photon (fluorescence). Under certain conditions (chemical, external fields, etc.), a nonradiative processes will raise the state to a less energetic triplet state. Once these molecules reach the lowest triplet state, they will remain in this state for an undetermined time. Under the low-probability triplet-singlet conversion processes, the molecules will emit LIGHT. The total energy stored in the molecule includes nuclear processes including VIBRATION and rotation of the nuclides as well. Under the assumption that the excited singlet state is close in energy to a triplet state, the molecule can make a singlet-triplet transition, exchanging energy with the environment through the vibrational modes (i.e., vibrational relaxation). After that it will decay to the bottom triplet state, followed by a triplet-singlet transition. The triplet-singlet and singlet-triplet transitions, in fact, both violate the $\Delta S = 0$ SELECTION RULE, AND are hence relatively slow (seconds–minutes, compared to a nanosecond scale and less for fluorescence). However, the $\Delta S = 0$

selection rule applies only to DIPOLE transitions, meaning that the phosphorescent, “glow-in-the-dark” objects in fact do not violate any laws (see [Figure P.64](#)).



Figure P.64 Phosphorescent jelly fish.

P Phosphorus (phosphor) ($^{30}_{15}\text{P}$)

[atomic, chemical, nuclear, solid-state] ELEMENT described first in 1669. Nonmetal, polyatomic. Phosphorus is found primarily in three forms: white, violet, and red, but is never discovered as pure substance due to its highly reactive nature (always bound, oxidized). Phosphorus is particularly known for its ability to emit visible LIGHT under the influence of incident short-wavelength ELECTROMAGNETIC RADIATION as well as certain energetic PARTICLE radiation. Electron bombardment provides the mechanism of action for visible light emission in photographic X-RAY detectors as well as the IMAGE formation on the face of the old-fashioned CRT (CATHODE ray tube) television/monitor screens (also found in oscilloscopes). Phosphorus is used in many

everyday chemicals, ranging from cleaning supplies to pesticides to nerve agents and in matches. Note: only the white phosphorus can oxidize and form light, not the red or violet phosphorus (see [Figure P.65](#)).



Figure P.65 Phosphorus as used in matches.

Photinus-luciferin 4-monooxygenase

[biomedical, chemical, optical, thermodynamics] Biological enzyme that is closely linked to the formation of ADENOSINE TRIPHOSPHATE (ATP, cellular biological renewable ENERGY form in macromolecule) that emits LIGHT at a very narrow bandwidth of around 562 nm. One particular form of emission is under chemical OXIDATION excitation: Photinus luciferin + O₂ + ATP Mg oxidized Photinus luciferin + CO₂ + AMP + diphosphate + 562 nm light, where Mg is a magnesium cofactor (chemical catalyst), and AMP represents adenosine monophosphate.

Photoacoustic microscopy

[acoustics, biomedical, imaging, optics] Hybrid imaging technique that relies on the excitation of phonons inside a medium by means of selective absorption of photons, photoacoustic effect. Photoacoustic imaging is nondestructive, high RESOLUTION, and has deep penetration. The acquired spatially resolved acoustic spectrum will yield information about the configuration of the local elastic moduli (also known as PHOTO-ACOUSTIC IMAGING). Photoacoustic imaging is based on the principle of LIGHT absorption that will generate elevated temperatures. Based on the Boyle–Gay–Lussac law, higher temperatures will lead to increased pressure, and from this it can be seen that a net increase in local volume can also be expected. Under pulsed laser irradiation, the short duration temperature rise can produce mechanical longitudinal shock waves. Combining the fact that light will penetrate deep into a medium and the localized generation of acoustic SHOCK WAVE, will produce an imaging system that may surpass the attributes and characteristics of both optical and acoustical imaging. The photoacoustic effect is described based on three equations, each with a range of unknowns. The first equation is the EQUATION OF RADIATIVE TRANSFER, describing the light distribution inside the target medium resulting from the pulsed light irradiation and the potentially nonlinear optical effects under these conditions. The resulting temperature generation and associated thermal effects (damage) are described by the heat equation. Finally, the EXPANSION with rising temperature and resulting acoustic wave propagation is defined through the WAVE EQUATION; in three dimensions with changing

boundary conditions due to the thermal effects and transient nature of the compression. Solving this problem analytically relies on clever choices for approximations, when possible. Generally during pulsed laser photoacoustic imaging the light is delivered over periods in the nano or femtosecond time frame, which creates several theoretically advantageous conditions. The equation of radiative transfer will incorporate the source function $S(\vec{r}, \vec{s})$, defining the laser beam incident on the medium under investigation, assuming standard Gaussian characteristics: $S(\vec{r}, \vec{s}) = I_0 \text{EXP}[-2r^2/w^2]$, where I_0 is the radiance at the center of the beam, w the beam waist, and r the radius from center of the beam. The time-dependent equation of radiative transfer can generally be solved by separating the anisotropic radiance in a direction-dependent term next to a diffuse term: $L(\vec{r}, \hat{s}, t) = (1/4\pi)\Psi(\vec{r}, t) + (3/4\pi)\Phi F(\vec{r}, \hat{s})$. Here, the symbol F defines the direction-dependent (i.e., diffuse) radiance. The fraction of ENERGY scattered to that removed from the radiance stream is indicated by the albedo: ω , for pure absorption $\omega = 0$, while for totally elastic, conservative SCATTERING $\omega = 1$, which is a function of optical depth. The diffuse fluence rate can be calculated based on the

DIFFUSION approximation of the equation of radiative transfer as

$(1/c)(\partial \bar{L}(\vec{r}, t)/\partial t) - \vec{s} \cdot \nabla \bar{L}(\vec{r}, t) + [\mu_a(\vec{r}) + \mu_s(\vec{r})]\bar{L}(\vec{r}, t) - \mu_s(\vec{r}) \int_{4\pi} p(\vec{s}, \vec{s}') \bar{L}(\vec{r}, t) d\Omega' = \bar{S}(\vec{r}, \vec{s})$. Under the preferential short pulse conditions, the source $\bar{S}(\vec{r}, \vec{s}, t)$ function for the laser pulse can be written as

$\bar{S}(\vec{r}, \vec{s}, t) = \delta(\vec{r})\delta(\vec{s})\delta(t)$; this is specifically allowed due to the fact that the thermal RELAXATION TIME is much longer than the pulse duration. Additionally, the SOLUTION for the equation of radiative transfer can be found under these conditions as a FOURIER SERIES. For example, using the speed of light

($v = 299792458/n_2$ m/s, n_2 the index of refraction for the medium [$n_2 = 1.35$ water]), within a laser pulse duration of 100 fs, the cluster of irradiating photons can travel approximately 22 μm . Generally, in a turbid medium there will be isotropic scattering, resulting in a significant DISPERSION. However, due to nonlinear effects and long wavelength (in the RED and near INFRARED), the scatter will be primarily in the forward direction with a scattering anisotropy factor of $g > 0.95$, providing only a slightly diverging beam. On the thermal aspects, assuming an output energy of only 9 nJ (commonly found for Q-switched lasers), the peak energy density will be 0.0076 J/cm², or 760 kW/m², heating up a focal volume. Generally, under these short-pulse conditions, only a slight temperature rise will be seen, avoiding vaporization and, depending on Young's modulus of the medium, also cracking can be avoided. In rigid media such as teeth, the potential for cracking under "long" pulse duration may still exist. The heat resulting from the laser light absorption will flow in the direction of any temperature gradient inside the sample. The steeper the temperature gradient, the more efficient the conversion from optical to acoustical energy. The instantaneous local temperature rise of the medium under the absorption of light is given by $\Delta T = \mu_a L / \rho C_p$. The temperature rise is directly proportional to the absorbed local light fluence rate $\mu_a L(\vec{r}, \vec{s}, t)$ divided by the local SPECIFIC HEAT C_p times the density ρ , where $L(\vec{r}, \vec{s}, t)$ is the local radiance of light, and $\mu_a(\vec{r}, \vec{s}, t)$ is the optical absorption coefficient for the medium as a function of location, direction of propagation, and time. The temperature development $T(\vec{r}, t)$ can be calculated from the heat equation, ignoring the influence of flow of the medium itself, or through the presence of irrigation channels (which will be BLOOD vessels in biological media). The heat equation is written as $\nabla(\kappa \nabla T(r, t)) = \rho C_p \left[(\partial T(r, t)/\partial t) + \tau (\partial^2 T(r, t)/\partial t^2) \right] - \mu_a L(r, t)$, where κ is the THERMAL CONDUCTIVITY and $\alpha_T = \kappa / C_p \rho$ is the thermal DIFFUSIVITY. In order to assess the full impact of the thermal LONGITUDINAL WAVE the thermal relaxation time $\tau = 1/4\kappa\mu_a^2$ needs to be considered. For ultrashort laser pulses the thermal relaxation is in the order of $\tau_T \approx 1 \mu\text{s}$. Any event shorter than the thermal relaxation time can be considered QUASI-STEADY STATE, which is the case for femtosecond laser pulses allowing the time component of the source function to be approximated by a Delta distribution. As a result the second-order terms in the mathematical description, with respect to time, become negligible.

The temperature distribution can hence be modeled by the HEAT TRANSFER equation as

$\nabla^2 T(\vec{r}, t) - a^2 [\partial T(\vec{r}, t)/\partial t] = -[S(\vec{r}, t)/\kappa]$, with boundary conditions $T(\vec{r}, 0) = T_0(\vec{r})$. The temperature solution follows in terms of GREEN'S FUNCTION ($G(x, t; \xi, \tau)$): $T(\vec{r}, t) = \int_0^t \int_V G(x, t; \xi, \tau) f(\xi, \tau) d\tau dV(\xi) - a^2 \int_V G(x, t; \xi, 0) T_0(\xi) dV(\xi)$, where $f(\xi, \tau)$ represents the heat source, modeled as a spatial

GAUSSIAN DISTRIBUTION $f(\xi, \tau) = -[(1-R)/\kappa\tau_p] \mu_a J \exp[-\mu_a \xi] \exp[-2\rho^2/\omega^2] \delta(t)$, where $\omega(\xi) = \omega_0 [1 + (\lambda(\xi - \xi_0)/\pi\omega_0^2)^2]^{1/2}$, R is the surface reflectivity, J is the laser FLUX (J/cm²), ω is the beam radius (cm), ξ_0 is the location of the minimum waist, λ is the wavelength, and τ_p is the laser pulse width. Under the short time approximation, the heat source is a POINT SOURCE with solution for the Green function:

$G(x, t; \xi, \tau) = -[a^2/4\pi(t-\tau)]^{3/2} (1/a^2) \exp[-a^2|\vec{r}-\vec{\rho}|/(t-\tau)]$, where $\vec{\rho}$ is the radius in the

“Greens-medium.” This yields the solution for the temperature under femtosecond laser-pulse RADIATION as $T = T_0 + (c_2 \sqrt{\pi} d_1 / 4 b_1^{3/2}) \exp[d_1^2 / 4 b_1]$, using the following abbreviations: $b_1 = (a^2 / 4t) + (2 / \omega^2)$, $d_1 = a^2 r / 2t$ and $c_2 = (1 - R) \mu_a J e^{-\alpha z} \exp\{-a^2 r^2 / 4t\} / 2 \sqrt{\pi t a r \kappa \tau_p}$. Two particular cases can be distinguished for the conditions of the media: (1) absorption > scattering (black-body); (2) scattering > absorption. For a “black-body,” all the light emitted by the laser will be absorbed on the surface of the medium, negating the need for solving the RADIATIVE TRANSFER equation. Introducing the thermal relaxation length: $\ell_T = \tau_T v_{th}$, where v_{th} is the thermal propagation velocity of the medium; the thermal DIFFUSION LENGTH $\ell_D = \sqrt{2(\alpha_T / v_{laser})}$, where v_{laser} is the laser repetition rate. All these conditions provide the platform for a confined process, both spatially and temporally. It can be shown that under confinement the THERMAL EXPANSION length will be much smaller than the diffusion length. Additionally, the thermal diffusion length is also smaller than the thermal relaxation length. These conditions provide the simplification that the second-order derivatives in most equations will become zero. This can be verified by making Taylor expansions for all the parameters, which yields infinitesimally small second- and higher-order terms. As a result the thermal diffusion/propagation can be neglected in the heat equation, which can be shown to hold true after the Fourier expansion of the quadratic initial heat equation. The heat equation hence reduces to $\rho C_p (\partial T / \partial t) = \mu_a L(r, t) \delta(t)$. The third declaration describing the temperature impact on the displacement and as such the longitudinal pressure WAVE is defined based on the medium parameters, including Young’s modulus E and the cubic expansion coefficient β (which is three times the linear expansion coefficient: 3α) delivering the displacement u as $\rho (\partial^2 u / \partial t^2) - [E / 2(1 + \nu_p)] \nabla^2 u - [E / 2(1 + \nu_p)(1 - 2\nu_p)] \nabla (\nabla u) = E\beta / 3(1 - 2\nu_p) \nabla \theta$. The parameter ν_p represents the Poisson ratio, the ratio of the transverse contraction strain to the longitudinal extension strain in the direction of the stretching force: $\nu_p = -\epsilon_{trans} / \epsilon_{longitudinal}$. The Poisson ratio is a material constant. In the “far-field” theoretical analysis of the ULTRASOUND photoacoustic IMAGE formation, the following assumptions will be made. These conditions will subsequently be adjusted and refined based on the observed deviations from these approximations (requiring an iteration process based on the lack of knowledge of the real local parameters; deviating from the assumed conditions): (1) All calculations are performed in the Fraunhofer region, that is, in the far field; (2) in the far field the waves can be treated as plane waves; (3) the square of the received acoustic AMPLITUDE is directly linearly proportional to the scattered energy; (4) the scattered acoustic longitudinal pressure wave pattern is weak relative to the “photothermal” generated instantaneous pressure. The pressure wave may be converted into displacement, since the pressure is directly proportional to the square of the displacement. The medium will oscillate with a local RESONANCE FREQUENCY (ν) that is defined by the characteristic length of the confined segments under consideration, the value of Young’s modulus (E_Y), and the local density distribution can be expressed as $\nu = C \sqrt{E_Y / \rho} (d / w \times b)$, with d the depth, w the width, and b the height of the structure of the medium. C denotes a constant that is a function of the MOMENT OF INERTIA (I) of the structure; alternatively, $\nu = A \sqrt{(E_Y I / m_\ell L^4)} \cong A' \sqrt{(E_Y / \rho L^2)}$, where L represents the length of the sides of a cube of the medium, m_ℓ is the mass per unit length, and A is a constant that depends on the mode of excitation. The use of the moment of inertia is justified since during the tissue expansion process a VORTEX will be formed. With respect to the vortex formation, there will be strain due to the change in volume (ΔV) with respect to the initial volume (V): $\epsilon = \Delta V / V$. This is inherently linked to the temperature jump, as described by the volume expansion coefficient: β , $\Delta V = \beta V \Delta T$, giving $\epsilon = \beta \Delta T$. The stress in the medium equals the force per unit area, which by definition describes pressure. Hence the pressure associated with this strain is expressed as $P = -K_{bulk} \epsilon$, where K_{bulk} represents the bulk modulus that specifies the pressure per unit strain. The photoacoustic wave equation in the medium resulting from the light absorption can be derived from the momentum equation, the EQUATION OF CONTINUITY, and the EQUATION OF STATE. The three equations reduce to the following three conditions: $[\partial \rho(\mathbf{r}, t) / \partial \tau] + \nabla \bullet [\rho \mathbf{V}(\mathbf{r}, t)] = -\int_0^h S(\mathbf{r}, t) / \mathbf{r}^2 \delta \tau$, $[\beta(\mathbf{r}) / \rho_0 C_0^3] \rho [\partial V(\mathbf{r}, t) / \partial \tau] - (V(\mathbf{r}, t) \bullet \nabla) V(\mathbf{r}, t) + \nabla \bullet P(\mathbf{r}, t) = \nabla S(\mathbf{r}, t)$, and $P(\mathbf{r}, t) = K \rho^q$. Here, $V(\mathbf{r}, t)$ is the displacement velocity and $P(\mathbf{r}, t)$ is the acoustic pressure amplitude of the primary (ultrasonic) wave. The acoustic propagation resulting from photoacoustic excitation and the associated imaging aspects are very similar to ULTRASONIC IMAGING. The main difference with ultrasound imaging is that under photoacoustic imaging the acoustic source is less well defined and requires specialized sensory placement and SIGNAL acquisition design techniques to gain access to the three-dimensional information. The initial pressure $P_0(\mathbf{r}, t)$, resulting from laser absorption is defined as $P_0(\mathbf{r}, t) = G_r K \beta [\mu_a \tilde{L}(\vec{r}, \vec{s}, t) / \rho C_p]$. Using the correction factor, G_r , which expresses the fraction of thermal

energy from the absorbed light that is converted into mechanical expansion. With photoacoustic imaging, soft biological media such as blood vessels can be mapped. Frequently, ultrasonic imaging of soft tissues in biology required the use of a chemical being inserted into the patient as a contrast enhancement that may become obsolete under photoacoustic imaging. Other diagnostic applications are in thin-film thickness determination and associated quality control in semiconductor manufacturing and the automobile and airplane industry.

Photobiological process

[biomedical, chemical, optics, thermodynamics] Light mediated biological/biochemical effect including the PHOTOSYNTHESIS in plants and animals, as well as photoperiodism, phototaxis, and phototropism. A very special class is VISION. Other extended applications are found under LOW-LEVEL-LIGHT THERAPY (LLT).

Photobleaching

[biomedical, chemical, optics] The optical modification of the electromagnetic characteristics of a MOLECULE. Often photobleaching involves the destruction of dyes, or the SATURATION of the absorption with resulting decrease in SCATTERING of LIGHT or specifically the reduction or extinction of fluorescent transitions. Photobleaching indicates the temporary loss of a fluorophore to fluoresce as a result of PHOTON-induced chemical damage and on a molecular level the covalent modification. The covalent modification consists of the saturation of the transition from an excited SINGLET STATE to the excited TRIPLET STATE. During the FLUORESCENCE process, fluorophores may be induced to interact with another molecule and inadvertently produce irreversible covalent modifications. The triplet state is relatively long-lived with respect to the energetic singlet state. Hence excited molecules will experience a much longer time frame to endure chemical reactions with environmental constituents. The average number of excitation and emission cycles allowed for a particular fluorophore is generally dependent on the molecular structure as well as the local environment. Certain fluorophores may bleach rapidly after emitting merely a few photons. Other molecules can perform millions of fluorescence cycles before bleaching. The deliberate extinction of fluorescence with the ensuing fluorescent recovery is one particular application of photobleaching used for physiological imaging in biological applications, specifically with respect to the protein binding analysis for the CELL MEMBRANE; called fluorescence recovery after photobleaching (FRAP) imaging (*also see* "FADING").

Photocathode

[electronics, imaging] Light sensitive negatively charged ELECTRODE that releases electrons when ELECTROMAGNETIC RADIATION is incident, such as that used in the design of a PHOTOMULTIPLIER TUBE. The electrode may be treated with specific materials to increase the sensitivity to LIGHT and encourage the PHOTOELECTRIC EFFECT on the surface, releasing an electron in free space.

Photochemical effect

[biomedical, chemical, optics] In VISION it has been shown that in contrast to the slow overall phenomenological mechanism of vision there are events in ROD and CONE sensibility that take place in the femtosecond and even picosecond range. The vision experience itself is however in the 20–100 Hz range for the various species. The physiochemical process of the PHOTOCHEMICAL EFFECT in the RETINA is in the same range as the PHOTOELECTRIC EFFECT.

Photochemical reaction

[biomedical, chemical, optics, thermodynamics] *See* LOW LEVEL LIGHT THERAPY.

Photocoagulation

[biomedical, optics] The conversion of PHOTON energy into MECHANICAL ENERGY (i.e., THERMAL ENERGY). The process describes the thermal denaturation of proteins to kill cells, either unwanted or potentially harmful, by means of destruction of the cellular membrane or the NUCLEUS of the CELL. The initial attempts

of the clinical use of photocoagulation can be traced back to the eighteenth century, by means of reflecting sunlight. Sunlight was channeled from the roof of the hospital in the operating rooms by means of mirrors and lenses. Prior to that, the healing potential of LIGHT was used by the Egyptians and Greek around the beginning of the western calendar. Other use of bright broad-band light such as the incandescent light or even still sunlight for clinical applications was in use for welding detached retina in the EYE, specifically in response to retinal detachment in diabetics in the early twentieth century. Other applications, also in the eye (primarily lending itself due to its optical transparency), were for the treatment of intraocular tumors. With the introduction of laser light, optical treatment procedures became more proficient due to the potential for selecting the most appropriate wavelength, resulting in minimized peripheral damage. The photocoagulation process specifically relies on the conversion of photon energy in thermal energy. The light absorption in the medium is a direct function of the light distribution as a function location with a tissue volume on a three-dimensional pattern, calculated using the TRANSPORT EQUATION or EQUATION OF RADIATIVE TRANSFER. Examples of other specific application of photocoagulation are wrinkle reduction/removal, tattoo removal, hair removal, and the removal of port-wine stains on human SKIN, and thermal superficial cancer tissue removal next to nonthermal deep cancer treatment (*see* PHOTODYNAMIC THERAPY), while minimizing the formation of scar tissue resulting from thermal burns to the peripheral tissues. Other applications are in tissue welding, providing an elegant manner for wound closure. Tissue welding is gaining popularity in the treatment of vascular diseases by a transcatheter approach. One particular application of vascular tissue welding is in anastomosis, joining vessels together that re-route the BLOOD flow, for instance in solving poor CIRCULATION in the legs or for SHUNT application in the arm, to be used during the process of connecting a patient to an external filtration system during KIDNEY dialysis. There are a number of ways to perform tissue welding: (1) through photothermal heating of the tissue itself, (2) by means of a solder or a photoactivated adhesive, or (3) by combining a LIQUID solder and a solid solder. Commonly used LIQUID solder agents are ALBUMIN and blood. Solid solders include insertion of biodegradable POLYMER thin films. To enhance the photoselective coagulation process, dyes can be used to achieve wavelength selective absorption. Direct laser welding relies on coagulating tissue proteins. The main advantage is that the tissues repair fast, with little or no foreign body reaction, and generally the seals are watertight. Disadvantages may be low acute strength, compared to a suture, and thermal damage to the tissue. The use of CHROMOPHORE-enhanced protein “solders” can augment the welding process, improving acute wound strength. Solders include polymers such as the biodegradable PLGA (polylactic-co-glycolic acid) as well as a liquid albumin solder. Additionally, the protein cross-linker genipin added to albumin solder results in a stronger tissue weld. Other welding agents are indocyanine green doped albumin (derived from bovine serum colored green to enhance absorption at the near INFRARED wavelengths used). Especially in vascular welding there is a frequent need for solder. Other factors involved in the welding efficiency are the thickness of the media d and the absorbed laser energy over the duration of exposure t . Before getting into the photothermal concepts, two definitions need to be introduced: enthalpy and entropy. Enthalpy H defines the energy of the chemical bonds between the atoms that constitute the molecules within the system. The entropy of the system is defined by the change in INTERNAL ENERGY divided by the temperature of the system at the time, as $dS = dQ/T$. The FIRST LAW OF THERMODYNAMICS postulates that energy cannot be destroyed nor generated. The work done on a system combined with the administered heat hence r is the temperature in kelvin and results in a change in internal energy: $dU = dQ - dW$. The laser/light energy deposited in the tissue will be absorbed and hence raise the local temperature. The energy deposition as well as the temperature rise can induce chemical reactions by means of changing the enthalpy of a system. The biological system consists of the atoms that form the complex molecules providing the building blocks of amino acids, carbohydrates, fats, and proteins. The deposited light energy is considered the reaction enthalpy, where the change in enthalpy is the final system enthalpy minus the enthalpy of the initial state of the system. TEMPERATURE EFFECTS OF LIGHT-TISSUE INTERACTION: the amount of photon energy conversion into thermal energy in the propagation process for the light in tissue is based on the absorption coefficient and the total attenuation coefficient. The locally generated temperature rise will result in heat flow due to a thermal gradient. The HEAT TRANSFER Q can be calculated at any given point in the tissue based on the local temperature gradient $\Delta T/\text{length} = [(d/dx) + (d/dx) + (d/dx)]T = \nabla T$, yielding $Q = -\kappa_T [(d/dx) + (d/dx) + (d/dx)]T = -\kappa_T \nabla T$, where T is the temperature in kelvin and κ_T is the THERMAL CONDUCTIVITY, on average $0.5 \text{ W m}^{-1} \text{ K}^{-1}$ for

water-based tissue. This heat transfer process is time dependent: $\rho c_V (\partial T / \partial t) = \nabla (k_T \nabla T)$, where ρ is the tissue density, for most tissues it is $1.04 \times 10^3 \text{ kg m}^{-3}$, and c_V is the heat capacity, approximately on average $3.7 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$. Incorporating the laser heat source q resulting from the light absorption gives $\rho c_V (\partial T / \partial t) = \nabla (k_T \nabla T) + q$, where q equals the rate of energy deposited in a volume of tissue cells, which is the local fluence rate (i.e., the location- and time-dependent light distribution) times the local absorption coefficient $\mu_a L(r, \theta, z)$. Additionally, in a full analysis the heat transfer resulting from blood perfusion should be included due to the abundance of blood vessels in all living tissues. Including blood perfusion in the energy balance for heat will incorporate the flow rate of the blood ω_b , in $\text{m}^3 \text{ kg}^{-1} \text{ s}^{-1}$; the density of the blood ρ_b ; the SPECIFIC HEAT of blood c_b ; and the heat exchange between the heated tissue and blood is based on the temperature difference between the blood and the surrounding tissue: $T - T_b$, to yield a blood flow heat loss as $-\omega_b \rho_b c_b \rho (T - T_b)$. Combining all the characteristics and phenomena describing the tissue temperature evolution as a function of time an expression can be obtained, known as THE HEAT EQUATION, respectively bioheat equation: $(\partial T / \partial t) = (1 / \rho c_V) [q + k_T [(\partial^2 / \partial x^2) + (\partial^2 / \partial y^2) + (\partial^2 / \partial z^2)] T - \omega_b \rho_b c_b \rho (T - T_b)] = (1 / \rho c_V) [k_T \nabla^2 T - \omega_b \rho_b c_b \rho (T - T_b) + q]$. In the process of raising the tissue temperature, other phenomena will take place, such as coagulation and EVAPORATION, which are both heat sinks that need to be accounted for. The coagulation process encompasses both a temperature rise and a PHASE TRANSITION. The phase transition for coagulation has a LATENT HEAT that is tissue specific: h_{coag} and is expressed in J kg^{-1} . The heat loss due to coagulation, Q_{coag} , is a direct function of the coagulated tissue volume V_i and the tissue density ρ , providing the coagulated tissue mass, defining $Q_{\text{coag}} = h_{\text{coag}} \rho V_i$. The heat loss due to evaporation is defined by the rate of water loss. Note that for cosmetic surgery the material under consideration may be either partially composed of fat or solely, with its own thermodynamic characteristics. The heat loss due to evaporation is the rate of evaporation multiplied by the latent heat of evaporation (water $h_{ev,W} = 2.26 \times 10^6 \text{ J kg}^{-1}$), which yields $Q_W = V_W (\rho_{W,\infty} - \rho_{W,S}) h_{ev,W}$, where V_W is the volume of evaporated water, $\rho_{W,S}$ is the mass density of saturated water VAPOR at the surface of the evaporation surface (e.g., vapor BUBBLE), and $\rho_{W,\infty}$ is the vapor mass density outside the biological tissue (i.e., cell). Because of the fact that evaporation inside the cell with the CELL MEMBRANE intact changes the internal pressure (sometime reaching several hundred ATMOSPHERE), thus affecting the thermodynamic parameters in the process as a dynamic system. The local metabolic heat generation can generally be neglected. Integration of the heat equation over a volume of tissue yields $V \rho c_V \partial T / \partial t = \iint_s k_T \nabla^2 T * \vec{n} \cdot d\vec{s} - V \omega_b \rho_b c_b \rho (T - T_b) + qV - Q_W - Q_{\text{coag}}$ where the volume of heated tissue has a surface area s , $\vec{n}$ is the normal to the surface of the area over which heat is radiated out, and Q_W and Q_{coag} are the rate of heat loss due to coagulation as well as evaporation (i.e., dehydration), respectively. Because of the DYNAMICS of the local light distribution and the changing thermodynamic parameter, the heat equation generally requires solving numerically by stepwise integration over time to produce the temperature distribution within the full length of the duration of laser irradiation. The tissue is therefore divided into volumetric units that are homogeneous and in steady state during the integration step duration. These volume ELEMENTS are called voxels. The VOXEL dimensions close to the laser impact will need to be smaller than that at large diffusion DISTANCE. This is referred to as a finite ELEMENT method in mathematical procedures. In the tissue, the volume element, voxel v_{ijk} , will yield a finite time description for the temperature, assuming in first-order noncompeting processes in three dimensions as $\partial^2 T / \partial x^2 = (T_{i+1} - T_i + T_{i-1}) / [(i+1) - i(i-(i-1))]$; $\partial^2 T / \partial y^2 = (T_{i+j1} - T_j + T_{j-1}) / [(j+1) - j(j-(j-1))]$; and $\partial^2 T / \partial z^2 = (T_{k+1} - T_k + T_{k-1}) / [(k+1) - k(k-(k-1))]$. Stepping through the NUMERICAL process will provide the change in temperature due to energy deposition by laser irradiation in tissue while accounting for all inherent losses. The next stage in the determination of thermal damage is the calculation of the degree of tissue degeneration as a function of local temperature MAGNITUDE and exposure time.

photocoagulation: coagulation can be reversible or irreversible. Whether a process is reversible or not depends on the total amount of energy delivered and the time frame over which the total amount of energy is administered. In general, chemical reaction takes place in infinitesimally small temporal steps and the ensuing changes in chemical composition take place gradually and can be considered reversible. In a reversible process, the system is always at equilibrium, and will revert to the starting conditions when no additional energy deposited, subsequently releasing the energy that was initially deposited. REVERSIBLE

PHOTOCOAGULATION: in a **REVERSIBLE PHOTOCOAGULATION** process the changes to the molecular bond configuration can revert back to the original state without resulting in a change in entropy. Histological examination may under these conditions reveal changes that are not classified as denaturation. Reversible damage constitutes cell membranes that are still intact and a surviving nucleus. Under normal conditions the reversibly damaged region will be equivalent to normal healthy tissue after a healing period. Typical proteins have an energy range in which they are stable. For instance, the range of stability between folded and unfolded protein strands is resilient from 7 to 15 kcal/mol of added heat at 37°C. This stability energy level is defined as the (Gibbs) free energy of the protein. **IRREVERSIBLE PHOTOCOAGULATION:** the process of **IRREVERSIBLE PHOTOCOAGULATION** is defined by either or both the destruction of the cell membrane and/or nucleus. Including the **SECOND LAW OF THERMODYNAMICS** it will follow that for an irreversible process in an **ISOLATED SYSTEM** the entropy will by definition increase: $\Delta S = S_{\text{final}} - S_{\text{initial}} > 0$. The molecular disorder associated with the increase in **ENTROPY** (S) has been defined by **LUDWIG EDUARD BOLTZMANN** (1844–1906) as the natural log of the number of all possible configurations within a system ω , multiplied by the Boltzmann constant: $S = k \ln \omega$. An equilibrium condition corresponds to $\partial S = 0$, where S represents the maximum attainable entropy. In order to describe the process of photocoagulation providing irreversible damage, the internal energy of the molecules that constitute the tissue needs to be considered. The change in internal energy of a system exposed to external influences is defined as the change in enthalpy for the molecular system $\Delta H = U + \Delta(PV)$, incorporating the work done by changing volume and/or pressure $\Delta(PV)$, which, under constant pressure, becomes the volume labor: $P\Delta V$. Incorporating the **IDEAL GAS LAW** ($PV = nRT$), this transforms to a chemical reaction: $\Delta H = U + \Delta nRT$, where Δn equals the change in molecules resulting from the (thermally induced) chemical reaction, and $R = 8.3144621 \text{ J/mol K}$ is the universal gas constant. The temperature of the system (T) is measured in kelvin. The enthalpy change in an **EXOTHERMIC REACTION** of a system is considered to be negative, which entails that the chemical reaction produces heat. **PHOTOCOAGULATION** will constitute an endothermic reaction, where heat is absorbed, rendering the change in enthalpy for the system positive. The change in free energy of the system (Gibb's free energy: G) combining the enthalpy and entropy and yields $\Delta G = \Delta U - T\Delta S - S\Delta T + \Delta nRT + nR\Delta T$. Building on this the chemical process of denaturation is described as follows: $\Delta G_{\text{den}} = \Delta H_{\text{den}} - T\Delta S_{\text{den}}$, which applying the chemical process $aA + bB = cC + dD$ $\Delta G = xJ$ yields $\Delta G_{\text{den}} = \Delta G_{\text{native}} + RT \ln \left[\frac{[C]^c [D]^d}{[A]^a [B]^b} \right]$, where $[A]$ and $[B]$ represent the respective native molecular concentrations, and $[C]$ and $[D]$ are the concentrations of the denatured states for the molecules involved in the respective processes. Using the fact that the entropy change ΔS_{den} will be positive, it can be shown that $\Delta S_{\text{den}} = k \ln \left(\omega_{\text{denatured}} / \omega_{\text{native}} \right)$, where ω_{native} is the fraction of native (protein) molecules and $\omega_{\text{denatured}}$ the fraction of ensuing denatured molecules resulting from the administered heat. The fact that the entropy change will be positive is the result of the fact that denatured proteins will have more configurations available than the native proteins: $\omega_{\text{denatured}} / \omega_{\text{native}} \gg 1$. In comparison, when the temperature is high enough, the change in free energy will be negative, implying that the denatured state is stable at high temperature and that the native state is stable at low temperature. In the process of photocoagulation, the energy deposited by the laser light is the activation energy used by the denaturation process. An example of the reaction process with hypothetical energy levels. The standard Gibbs energy difference between the transition state from **GROUND STATE** to product for the reactants is calculated from the experimental rate constant k_r based on the conventional form of the Eyring absolute rate equation. The **EYRING ABSOLUTE RATE EQUATION** relies on the fact that the energy for each reaction is subject to **QUANTUM THEORY** due to the discrete nature of the chemical reactions: $\Delta G = RT \left[\ln(k/h) - \ln(k_r/T) \right]$, where k is the Boltzmann constant and h the **PLANCK CONSTANT** ($k/h = 2.08358 \times 10^{10} \text{ K}^{-1} \text{ s}^{-1}$). The values of the rate constants, and hence Gibbs energies of activation, will depend on the choice of concentration units, and the choice of thermodynamic ground state of the chemical medium. The standard enthalpy of activation for the process is $\Delta^\ddagger H^0$, which represents the enthalpy change in the rate equation obtained from conventional transition state theory. Alternatively, the quantity $\Delta^\ddagger S^0$ represents the standard entropy of activation. Solving the chemical process for change in molecular quantity, Δn yields an expression for the **PROBABILITY** of conversion between the native protein state and the denatured state k_r , defined as $k_r = (kT/h) e^{\Delta^\ddagger S^0/R} e^{-\Delta^\ddagger H^0/(RT)}$, also written as $k_r = A' e^{-E^*/(RT)}$.

The empirical reaction constants A' and E^* can be defined based on the fact that the rate of change for the transition from the native protein state to the denatured state takes place at kT/b ; this provides $A' = (kT/b)e^{\Delta S/R}$ and $E^* = \Delta H$. Generally, these constants are experimentally determined since there is not merely a single MOLECULE involved in the denaturation process for a biological specimen. The denaturation process is verified either by functional analysis (in situ) or by identified of histological markers of nuclear destruction. DAMAGE INTEGRAL: the numerical expression for achieving irreversible tissue damage can be derived from the so-called damage integral. The damage integral calculates the loss of normal tissue based on a standard reaction equation, transforming into the denatured state:

$\Omega(t) = \ln[N_{\text{total}}] / ([N_{\text{total}}] - [N_{\text{denatured}}]) = A' \int_0^t \exp(-E^*/RT) dt$, where $[N_{\text{total}}]$ defines the total number of cells in the tissue volume that is subject to irradiated by light and $[N_{\text{denatured}}]$ the number of denatured cells post laser irradiation. On a more complex scale, this is defined as follows. When there are initially N_0 molecules of one molecular species in a volume of tissue, the number of surviving molecules is proportional to the native number, and the rate of denaturation dN obeys the heuristic equation $dN = k_r N dt$. The number of surviving native molecules as part of the denaturation process as a function of time is defined as $N(t) = N_0 e^{-\Omega(t)}$, where $\Omega(t) = \int_0^t k_r(t') dt' = \int_0^t [kT(t)/b] e^{\Delta S/R} e^{-\Delta H/(RT(t))} dt'$. The expression $\Omega(t)$ is called the damage integral for the coagulation process. At any time during the photocoagulation process, the number of denatured molecules, $N_{\text{denatured}}(t)$, equals $N_0 - N(t)$. Thus, the damage integral incorporates the average values of all molecules involved in the denaturation process but specified by tissue section. The rate value k_r depends on the temperature of exposure and the values of ΔS and ΔH , which are characteristic for most measurable transitions in the chemical processes for the respective tissue. Examples of chemical transitions are the coagulation of egg white (cooking an egg, which may be performed by MICROWAVE ELECTROMAGNETIC RADIATION), the irreversible loss of enzymatic ACTIVITY that involves denaturation of labile proteins, and the whitening of soft tissues such as MUSCLE or LIVER during cooking (grilling out, frying pan, or using electromagnetic radiation: INFRARED lamps, laser, microwave). Each of these processes involves denaturation as well as the AGGREGATION process for proteins. The coagulation of collagenous tissue will yield gelatin, which involves the loss of collagen fiber bundle structure, such as that used for wrinkle removal. The rate constant k_r at a given temperature will have a value that is specific for different transitions. For example, second-degree burns can be captured by a value $\Omega > 10$, and for third-degree burns the value $\Omega > 10000$ is generally accepted. The more complex the molecular structure that is involved in the denaturation process, the steeper the change in rate constant with temperature. This change is due to the fact that the change in entropy (ΔS) is greater in addition to the fact that the number of bonds are being broken concurrently at a larger number (ΔH). The rate constant k_r for each tissue will vary as a function of temperature. In the denaturation process, generally the exposure time (t_Ω [s]) required to achieve $\Omega = 1$ is one of the parameters of interest. This exposure time is by definition $k_r = 1/t_\Omega$. When denaturing a less structured tissue, the chemical matrix will DECAY more gradually, with an associated change in rate constant due to the less vigilant changes in ΔS and ΔH in response to the temperature changes. The molecular structure involved in an irreversible thermal transition (denaturation) has in first-order approximation an entropy ΔS release linearly related to the enthalpy change ΔH for that particular transition. The enthalpy change ΔH describes an independent variable that is conceptually integral to the energy of all bonds that cooperatively provide the cohesive force for a molecular structure. The increase in entropy is generally considered to be a dependent variable, associated with the bond-breaking energy change. Examples of published average empirical values for tissues are skin $E^* = 627 \text{ kJ mol}^{-1}$, $A' = 3.10 \times 10^{98} \text{ s}^{-1}$; and collagen $E^* = 89 \text{ kJ mol}^{-1}$, $A' = e^{130} \text{ s}^{-1}$. The DAMAGE STATE: the damage region $0 \leq \Omega(t) \leq 0.53$ is generally considered to be reversible, or rather will not cause any (permanent) damage whatsoever to the tissue. The damage range $0.53 < \Omega(t) < 5$ will provide tissue coagulation. Generally, $\Omega(t) < 1$ can be used to define reversible tissue damage. A value of $\Omega(t) = 4.6$ represents the condition providing 99% probability of tissue denaturation. At $\Omega(t) > 5$, the tissue is susceptible to carbonization. Based on this, the following timelines can be projected for exposure to extreme solar energy (desert conditions): a second-degree burn resulting from skin

exposure to 135°C yields a time exposure of approximately 2.5 min, while a third-degree burn can be expected after exposure lasting in excess of on the order of 1 day and 18 h. The time–temperature correlation associated with final irreversible damage is one critical factor in the assessment process with respect to the thermal damage (see Figure P.66).

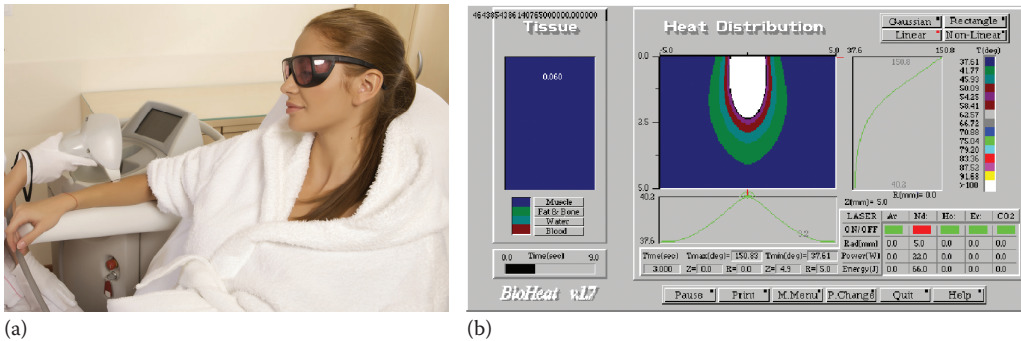


Figure P.66 (a) Port-wine stain removal. (b) Photocoagulation process for port-wine stain computational model.

Photocopy

[general] Process that transfers a charge density image of a real paper image over on role that is coated with ink, with ink density proportional to charge density, from which the ink is transferred to paper in a printing process: rolled over the paper (Xerox process). The charge distribution is achieved through a corona process, which generates an intense flash of LIGHT that ionizes the photographic role or alternatively the paper directly. Alternatively, the paper itself is ionized and the ink (toner) is directly transferred to the paper (electrostatic process). The charge density is the result of an ionic transfer process based on a flash discharge (corona) in the early devices. The process is used to generate a gray-scale/black and white copy of an illustration or object. The photocopy process has evolved to the use of laser scanners to scan original paper or object that is targeted for image formation on paper. The transfer of ink to regular paper has an efficiency of better than 90%. Dry paper can hold a charge distribution for several seconds, allowing the charged toner (ink) to adhere in a proportional fashion. The fusing process following the deposition will make the IMAGE permanent. Fusing can be accomplished by pressure, which is generally achieved by running the paper between two hot rollers. The FUSION process with the paper takes place at around 130°C . Thermal fixation with radiant heat alone is not very efficient due to the reflectivity of most paper materials. In a more elaborate process, the use of a spray-on fixative (e.g., EVAPORATION) is applied prior to the pressure roller process. The same process is used to transfer an image into a two-dimensional digital array for FAX transmission. The machine that performs the process is called a photocopier. Photocopy MACHINES are also known as Xerox machine, based on the success of the largest manufacturer, and patent holder, in the early glory days. The dry photocopy process was first introduced in 1938 by the physicist Chester Carlson (1906–1968), working for the Haloid Photographic Corporation, renamed to the Xerox Corporation in 1961. The dry process stands in contrast to wet printing used in the early days of newspaper printing where an etched plate is wetted with ink that is transferred to paper. The etched plate is mounted on a roller, which allows multiple prints with the identical image to be generated without the need for elaborate technology. The earliest form of physical paper printing from a

carved plate (wood plate to be exact) is documented to have been performed in China around the year 200. The automated printing press dates to 1453 (*also see* LITHOGRAPHY) (see [Figure P.67](#)).

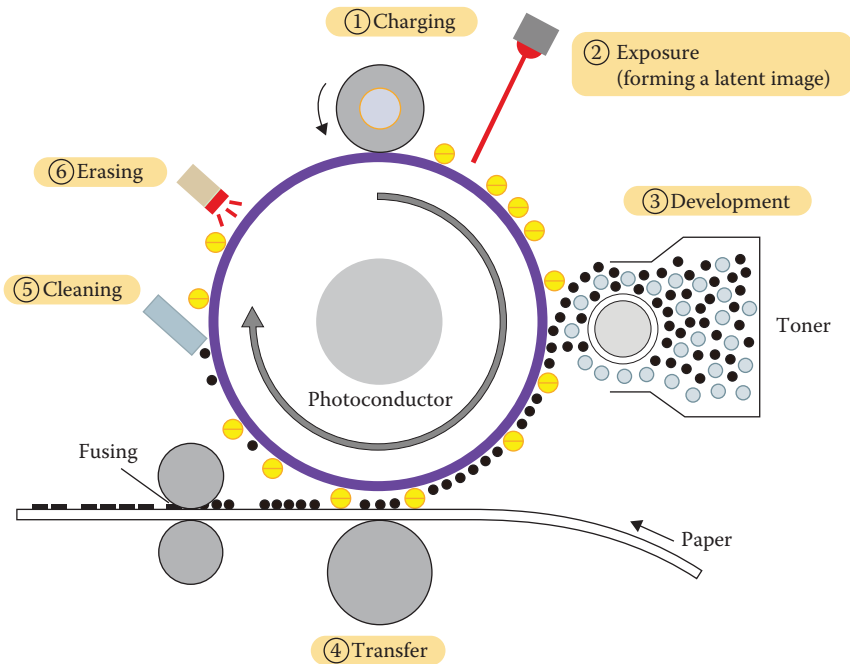


Figure P.67 Photocopy process: (1) Charging—the surface of the photoconductor is uniformly charged by the charging device; (2) Exposure—the document to be copied is illuminated and its image projected onto the photoconductor to form a latent image; (3) Development—the charged toner particles are attracted to the latent image, forming a visible image on the photoconductor; (4) Transfer—the toner image is transferred to the paper. In other step, the toner image is permanently fused to the paper; (5) Cleaning—Any remaining toner is removed from the photoconductor surface; (6) Erasing—the photoconductor surface is exposed to light to remove any remaining electrostatic charge. (Courtesy of Fuji Xerox.)

Photocurrent

[general] Electron current resulting from interaction of ELECTROMAGNETIC RADIATION with a material. The material can be artificial or natural. Examples are zinc as a natural material or silicone and germanium as a man-made medium (*see* PHOTOELECTRIC EFFECT).

Photodetector

[electronics, optics] Device that converts ELECTROMAGNETIC RADIATION into electrical current by either releasing valence electrons (i.e., PHOTOCURRENT) or by generating an electrical potential (electromotive force) that will generate a flow of electrons when a circuit is completed. Examples of photodetectors are photoconductors, junction photodetectors, and avalanche photodetectors. Photoconductors will change resistance under the influence of electromagnetic RADIATION, moving additional electrons to the VALENCE BAND. Junction photodetectors are for instance the SCHOTTKY DIODE, respectively layered Positive-Intrinsic-Negative doped (PIN) diodes, and Metal-Semiconductor-Metal (MSM) stacked diode. Avalanche photodetectors operate based on

ionization efficiency, more specifically the difference in ionization between two materials. The IONIZATION process is the result of the quantum-well mechanism (see [Figure P.68](#)).



Figure P.68 Microchip light sensor.

Photodisintegration

[atomic, nuclear] High-energy electromagnetic interaction on a NUCLEON level. The interaction cross-section can be described using Lorentz invariance as $\int_0^\infty [\sigma^p(k) - \sigma^A(k)] dk/k = 2\pi^2 \alpha S_i [K_i/m_i]^2$, where $\sigma^p(k)$ is the inelastic photon CROSS SECTION for polarized LIGHT parallel interacting with the target spin (S_i), $\sigma^A(k)$ is the inelastic PHOTON CROSS SECTION for polarized light on antiparallel interacting with the target spin, K_i the anomalous MAGNETIC moment of the target, m_i the target mass, $k = 2\pi/\lambda$ the wave-number, λ the wavelength, and α a condition constant. One specific interaction is described for the photo-disintegration of a DEUTERON.

Photodynamic therapy (PDT)

[biomedical, chemical, energy, optics] The use of LIGHT to affect biological properties. The use of light to treat medical conditions and general SKIN disorders has been documented as far back as approximately 1550 BC in the Ebers papyrus to treat pigmentation disorders assumed to be associated with leprosy. The PDT applications for clinical use on smallpox was described by the physician HENRI DE MONDEVILLE (1260–1320). More in-depth work on photodynamics interaction was described by OSCAR RAAB (1876–1986) and his work under the guidance of Hermann von Tappeiner (1847–1927) based on the PHOTOTOXICITY by Marcacci in 1888. In cancer treatment, photodynamic therapy uses a chemical mediator

that produces unstable and aggressive singlet oxygen, which rapidly oxidizes cells and effectively kills the cell. The efficacy of the photodynamic therapy is dependent on the wavelength of the light used with respect to the activation biochemical as well as the tissues the light is required to pass through to reach the target locations below the surface of the biological medium. The photosensitizer must adhere to several criteria to ensure efficiency: selective uptake in the tumor, activation by specific wavelengths that will penetrate deep into the tissue. The photochemical cannot be toxic by itself, and it has to have the capability to destroy malignant tissue growths once activated. The effectiveness of the photosensitizer depends largely on the localization of the drug in the tumor, and the light transmittance of the tissue that surrounds the tumor, at the activation wavelength. The PDT treatment is hence a function of the SOLUTION to the EQUATION OF RADIATIVE TRANSFER, as well as the conversion efficiency on a chemical level. One particularly important clinical application of PDT is in brain tumor. Generally, the spear and uptake of the photosensitive dyes (i.e., photoporphyrins) are not selective and will easily be distributed wherever BLOOD flow is available, thus using the local perfusion as an indication of the local photoporphyrin concentration. Certain photoporphyrins are designed to selectively bind to brain tumors, taking advantage of certain modifications in the blood–brain BARRIER due the tumor presence. Under normal/healthy conditions the photochemical will not be allowed to pass the blood–brain barrier based on the PHYSIOLOGY of this particular part of the CIRCULATION (see [Figure P.69](#)).

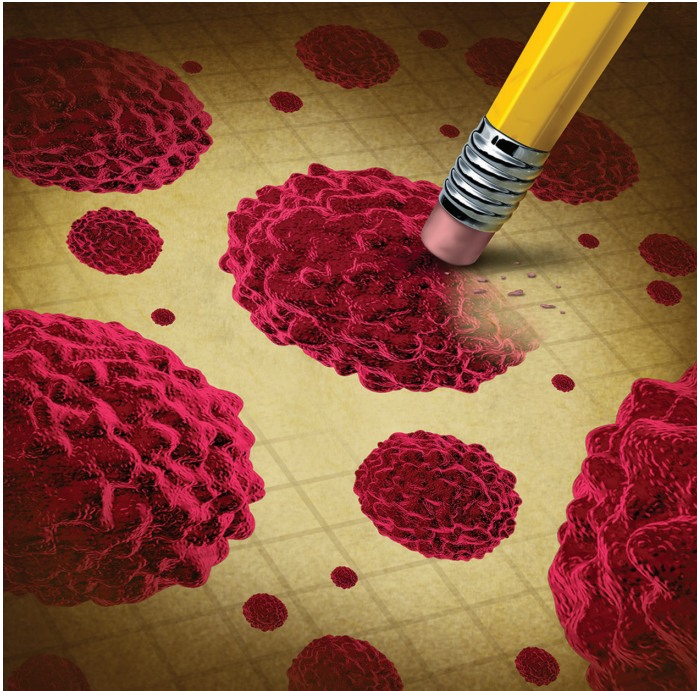


Figure P.69 Photodynamic laser therapy for cancer treatment using deep penetrating light and photoactivated chemicals that are concentrated in the cancer tissue volume.

Photoelasticity

[optics, mechanics] A material property with respect to the optical characteristics of an anisotropic medium wherein incoming single beam of unpolarized LIGHT enters into an medium where at the interface it is split into two rays traveling in different directions. The primary ray (called the ordinary ray) will be transmitted through the medium unchanged. A second ray is also formed in the BIREFRINGENCE process called the extraordinary ray, which is refracted at an ANGLE and will emerge at a different angle and location from the

opposite side of the medium. Examples of materials that are naturally birefringent are calcite crystal, frozen water (ice), sapphire, QUARTZ, and a wide selection of PLASTICS. Under the concept of *photoelasticity* optically transparent materials that are ordinarily not double refracting (birefringent) can be made to be birefringent under influence of applied stress. Examples of such materials are certain types of GLASS (BK7), CELLOPHANE, lucite and BAKELITE. The optical change, specifically the mechanically induced photoelasticity, can be used for quality control issues, highlighting location-specific discontinuities in the transparent patterns, specifically the spectral distribution, and potentially the changes in POLARIZATION angle of the transmitted light. These discontinuities will be cause for rejection or will require additional investigation for mechanical consistency. In this field, the following terms are used to define the optical characteristics of the medium: linear birefringence, circular birefringence, uniaxial, biaxial, and chiral birefringence. A special form of birefringence is Brillouin SCATTERING in birefringent media. Additionally, gyrotropic media become isotropic media under the influence of an external constant MAGNETIC FIELD. Examples are Earth's IONOSPHERE (furthermore, various plasma conditions), semiconductor materials, ferrites, and specialty fiber-optics. Additionally, the POCKELS EFFECT (after the German physicist FRIEDRICH CARL ALWIN POCKELS [1865–1913]), who in 1893 discovered that a steady electric field or a varying electric field applied to certain materials will induce birefringence by causing the refractive index to vary (*also see* KERR EFFECT). The practical application of the Pockels effect is applied to Pockels cells providing the mechanism of operation for Q-switched lasers (*also see* BIREFRINGENCE) (see Figure P.70).

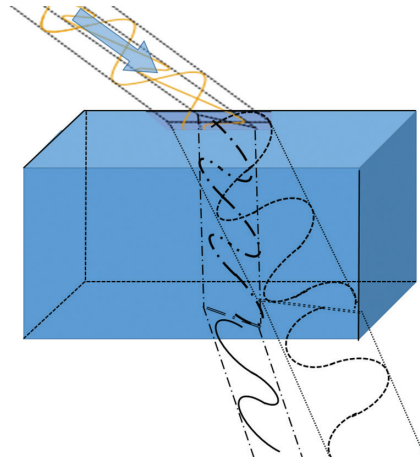


Figure P.70 Photoelasticity.

Photoelectric cells

[atomic, nuclear] Device for which the electrical characteristics are a function of incident LIGHT, providing electromotive force. Specifically, the conversion of ELECTROMAGNETIC RADIATION into electric ENERGY, producing a voltage (V_{EMF}) as a function of radiance. The mechanism of action depends on the PHOTOELECTRIC EFFECT. Additionally, the electrical RESISTANCE may change linearly with the incident radiance, hence providing a mechanism of measuring the MAGNITUDE when connected to a voltage source and a GALVANOMETER (VOLTMETER). As was described in 1897 by JOSEPH JOHN THOMSON (1856–1940), who showed that the

increased electrical sensitivity of material was caused by “light pushing on electrons” (also referred to as PHOTOCELL) (see [Figure P.71](#)).



Figure P.71 Photocell, semiconductor device relying on photoelectric effect (i.e., photovoltaic effect) to generate electricity, c.q. electrical potential.

Photoelectric effect

[biomedical, energy, nuclear, optics] The conversion of ELECTROMAGNETIC RADIATION ENERGY into kinetic energy of a loosely bound electron (i.e., VALENCE electron) culminating in the emission of a free electron from the ATOM providing the opportunity to initiate the flow of electrons and hence produce current. The PHOTON ENERGY will need to exceed the WORK FUNCTION (ϕ_{elec} , in electron volt eV) of the material in question. The relationship between the work function of the material/metal exposed to LIGHT (with energy $h\nu$, where $\nu = c/\lambda$ is the frequency of electromagnetic radiation with wavelength λ traveling at the speed of light: c and $h = 4.13567 \times 10^{-15} \text{ eV} = 4.1356692 \times 10^{-15} \text{ Js}$ is PLANCK'S CONSTANT) and the electron energy (KE_e) is expressed as $h\nu = \text{KE}_e + \phi_{\text{elec}}|_{\text{Metal}}$. Hence the threshold for the photoelectric effect is provided by $\nu_0 \geq \phi_{\text{elec}}/h$. The PROBABILITY of photon-electron interaction increases with: $h\nu \xrightarrow{\text{approaches}} E_B$, or: $\nu \xrightarrow{\text{approaches}} \nu_0$, where $\nu_0 = E_B/h$ is the frequency of the ABSORPTION EDGE resulting from resonant interaction with the orbiting electron, revolving with NATURAL FREQUENCY: ν_0 at BINDING ENERGY E_B . Under certain specific conditions the simultaneous capture of more than one photon, each at below threshold energy levels, can still result in a multiphoton photoelectric effect. The cumulative energy of multiple photons will exceed the threshold conditions. This is primarily reserved for ultra-short pulsed LASER irradiation, with inherently high RADIATIVE EMISSION per pulse (RADIANCE in order of MW per pulse) (see [Figure P.72](#)).

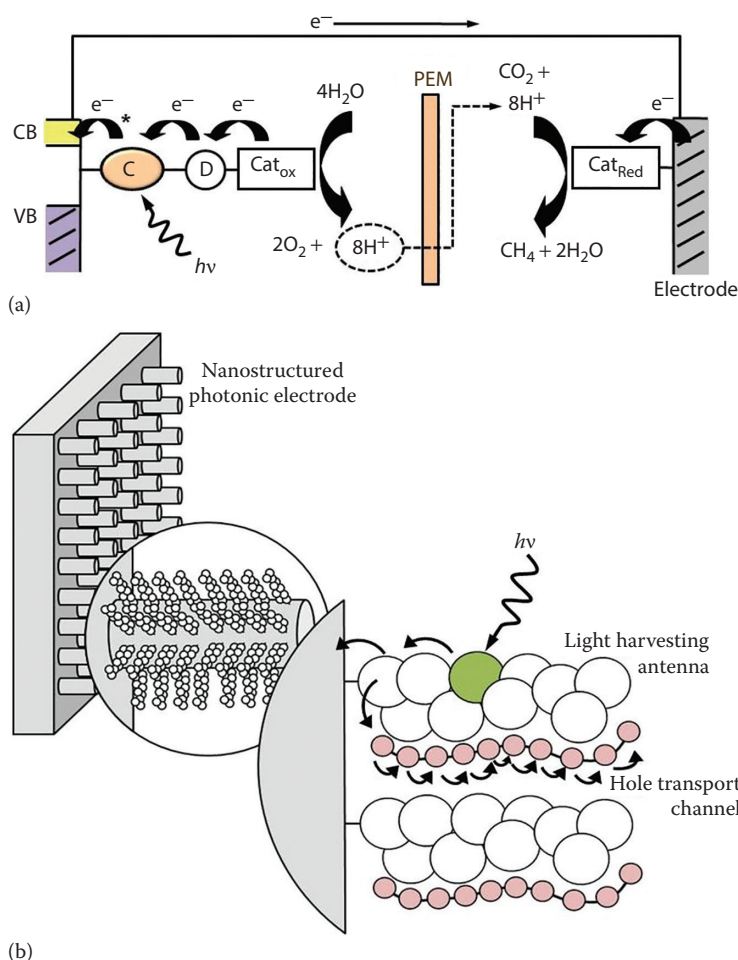


Figure P.72 Work performed at the University of North Carolina at Chapel Hill in biological photovoltaics. (a) Schematic showing a modular approach to a process termed artificial photosynthesis. The “artificial photosynthesis relies on similar principles as used by plants, absorbing sunlight and using those photons to split water that provides the protons and high-energy electrons needed to reduce CO_2 to make plant parts (carbohydrates). Modifying the photovoltaic mechanism of action of nature with dye-sensitized solar cell technology to make a dye-sensitized photoelectrosynthesis cell (DSPEC) is shown in schematic form. PEM stands for proton exchange membrane, C stands for chromophore (a.k.a. light absorber), D stands for donor, Cat_{ox} stands for catalyst designed for oxidation (e.g., water oxidation catalyst), Cat_{red} stands for catalyst designed for reduction (e.g., CO_2 reduction catalyst), CB stands for conduction band, and VB stands for valence band. Strictly speaking, D is not a requirement, just might help the device to separate redox equivalents at the two catalysts. (b) Schematic showing a new approach to photovoltaics by incorporating a light-harvesting antenna capable of very rapid energy transfer down to the surface of the electrode. The nanostructured photonic electrode also serves to trap light for higher efficiency, capturing much light as in comparison to the structure and working function of a butterfly’s wing. (Courtesy of Kyle Brennaman, University of North Carolina Chapel Hill; Chapel Hill, NC.)

Photoelectric equation

[general] Definition of the kinetic ENERGY (E_k) of an electron emitted from a METAL as a result of the absorption of a radiation QUANTUM as a function of the electromagnetic FREQUENCY (ν): $E_k = h\nu - \omega_w$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ is PLANCK’S CONSTANT, and ω_w the work function of the metal, as introduced by ALBERT EINSTEIN (1879–1955) in 1905. The PHOTOELECTRIC EFFECT was first observed by HEINRICH HERTZ (1857–1894) in 1887 during his experimental work on RADIO receivers with a spark-gap GENERATOR.

Photoelectric nuclear effect

[nuclear] In nuclear PHYSICS, it can be annihilated by means of gamma radiation. The condition is that the photon ENERGY $E_{\text{photon}} = h\nu$ needs to exceed the BINDING ENERGY of the PARTICLE involved. One specific example is the disintegration of DEUTERON, ${}_2^1\text{D} + h\nu \rightarrow {}_1^1\text{H} + {}_0^1\text{n}$, producing hydrogen and a NEUTRON. Additionally, this phenomenon has been recreated for beryllium. An additional phenomenon describes the pair production under the passage of a GAMMA RAY close to the NUCLEUS; a PHOTON with energy $E_{\text{photon}} = h\nu > 1.022\text{ MeV}$ can produce two “electron particles:” electron and positron, each traveling in perfectly opposite direction, with respective energy $E_{\text{positron}} = 511\text{ keV}$, which is the mechanism of action for pair production in POSITRON EMISSION TOMOGRAPHY (PET).

Photoelectron

[general] Electron released from METAL under influence of ELECTROMAGNETIC RADIATION (see PHOTOELECTRIC EFFECT).

Photographic plate

[chemical, general, optics] Surface coated with a light-sensitive emulsion that changes its transparency or REFLECTION after exposure to LIGHT, primarily resulting from oxidation, for example, silver chloride, which is converted to. The principle of chemical photographic (i.e., light-sensitive oxidation) sensitivity was discovered by the chemist (alchemist) Georg Fabricius in 1556; that is, LUDOLF GEORG GOLDSCHMIED, Prussian-German chemist (1526–1581) in his publication “De Rebus Metallicis” related to the darkening of “horn silver” [silver chloride] under exposure to light. Another photographic emulsion is silver nitrate with calcium. In 1777, the Swedish scientist and chemist CARL WILHELM SCHEELE (1742–1786) discovered that silver chloride has wavelength-dependent light sensitivity, primarily related to the difference between OXIDATION resulting blue light with respect to the longer wavelengths of the visible light (see [Figure P.73](#)).



(a)



(b)

Figure P.73 (a) Old-style studio camera with objectives and a framework for viewing photographic plate and (b) Georg Fabricius (Goldschmidt: 1526–1581).

Photography

[biomedical, imaging, optics] The process of producing an IMAGE on a plate based on incident ELECTROMAGNETIC RADIATION originating from a set of real objects, respectively transmitted through a real object (e.g., X-RAY radiation). The imaging system can be analog, using silver halide crystals as the image-forming medium (photographic film; CELLULOSE ACETATE film), or digitally based on charge-coupled device technology PIXEL array (digital CAMERA). The word “photographie” was first used by the French scientists Joseph Nicéphore Niépce (1765–1833) in 1826 and is known for his pioneering efforts in the development of photography with the first photograph displayed in 1825. The great deal of effort was contributed by the scientist and inventor from the United States, GEORGE EASTMAN (1854–1932) commercialized by the Eastman-Kodak corporation, known as Kodak (see Figure P.74).



Figure P.74 The art of photography exemplified by a high-speed frame capture (“freeze-frame”) of tea being spilled from a cup.

Photomultiplier tube

[atomic, nuclear] VACUUM tube that uses a cascade system to increase the number of electrons released from the incident PHOTON by means of the PHOTOELECTRIC EFFECT. Several plates positioned in a sequence are under a potential difference, which accelerates the initial PHOTOELECTRON to the second plate where additional electrons are released by collision impact. $E_k = h\nu - \omega_m$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ is PLANCK’S CONSTANT and ω_m the work function of the METAL (specific for photon interaction), as introduced by ALBERT EINSTEIN (1879–1955) in 1905, which is primarily a function of the electromagnetic FREQUENCY (ν) of the incident RADIATION. The number of secondary electrons released by the collision is a direct function of the electron kinetic ENERGY, which depends on the electrical potential between the plates: $E_k = k_e \left(\frac{e^2}{r} \right) - \omega_{m,c}$, where $k_e = 1/4\pi\epsilon_0$ is the Coulomb constant with $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space, $e = -1.60217657 \times 10^{-19} \text{ C}$ is the electron charge, r is the separation between the subsequent plates in the photomultiplier (dynodes), and $\omega_{m,c}$ is the release energy of the metal under collision. Generally, a single photoelectron can generate up to 10^7 secondary electrons, finally detected on the terminal ANODE, which are quantified by a GALVANOMETER (VOLTMETER). PHOTOMULTIPLIER TUBES have an inherent high internal gain and are extremely sensitive detectors for low-radiance detection applications;

however, they are relatively large and require an elaborate power supply, operating at a high negative voltage, typically ranging from -500 to -1500 V (see [Figure P.75](#)).



Figure P.75 Photomultiplier tubes inside a drum scanner.

Photon

[atomic, general, optics, quantum] Quantity of ENERGY emitted in the form of ELECTROMAGNETIC RADIATION with a value that is the product of its FREQUENCY (ν) and PLANCK'S CONSTANT ($h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$): $E = h\nu$ (quantum of LIGHT), this has a continuous distribution spectrum. The photon is the result of a charge OSCILLATION, where the ELECTRIC CHARGE (q) carries an electric field (E_{elec}), while the MOTION of the charge generates an alternating current (I , with the same frequency as the oscillation; FARADAY LAW): $I = I_0 \sin \omega t = dq(\vec{r})/dt$, where $\omega = \nu 2\pi$ is a function of charge location $\vec{r}$, which is the essential component to induce an associated and frequency matching alternating MAGNETIC FIELD ($\vec{B}$) (AMPÈRE'S LAW: $\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I$, where the integral is taken over a loop around the current, and $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$ the permeability of free space). The energy of the photon is expressed by the Pointing vector. The vector direction of the electric field defines the POLARIZATION of the electromagnetic radiation. Photons are generally described by the WAVE–PARTICLE DUALITY principle. Sometime treating the photon as a PARTICLE provides the essential mechanism for the process, for instance REFLECTION. Whereas the wave phenomenon is more suitable for several other interactions, for instance diffraction and INTERFERENCE. The particle theory dates back to the ancient Greek philosophers (starting as far back as Aristotle [384–322 BC]), but SIR ISAAC NEWTON (1642–1727) formally introduced his corpuscular hypothesis. The first formal

introduction of the wave theory of light was introduced by the Dutch scientist CHRISTIAAN HUYGENS (1629–1695). Photons span the entire ELECTROMAGNETIC SPECTRUM (see Figure P.76).



Figure P.76 The elusive photon.

Photopic vision

[biomedical, optics] Part of the three main modes of human vision: photopic, scotopic, and mesopic. Photopic vision represents VISION under brightly lit conditions. Photopic has COLOR perception, encompassing all functions associated with the cone cells in the retina of the EYE. Scotopic vision is black and white vision (“intensity” [magnitude] only. *Note:* intensity is technically not appropriate for ELECTROMAGNETIC RADIATION due to the duplicity of the nature of LIGHT, intensity is the AMPLITUDE squared) under low-light radiance conditions, attributed to the rod cells in the RETINA. Mesopic vision combines the low-level rod vision and bright cone vision, a combination of photopic vision and scotopic vision (see Figure P.77).



(a)



(b)

Figure P.77 (a) Photopic vision under bright sunlight and white reflecting buildings and (b) in comparison mesopic vision under artificial lighting in a grocery store.

Photosphere

[astrophysics/astronomy, geophysics] Solar layer, consisting of a PLASMA-nuclear reaction medium, primarily responsible for the LIGHT emission, the corona. The photosphere of our SUN is approximately 600 km thick. While brighter and hotter stars will have a thicker photosphere, it is estimated that the thickness is

generally $1/1000$ of the total radius of the solid STAR. The composition of the photosphere s generally inferred from the emitted Fraunhofer spectrum (see [Figure P.78](#)).

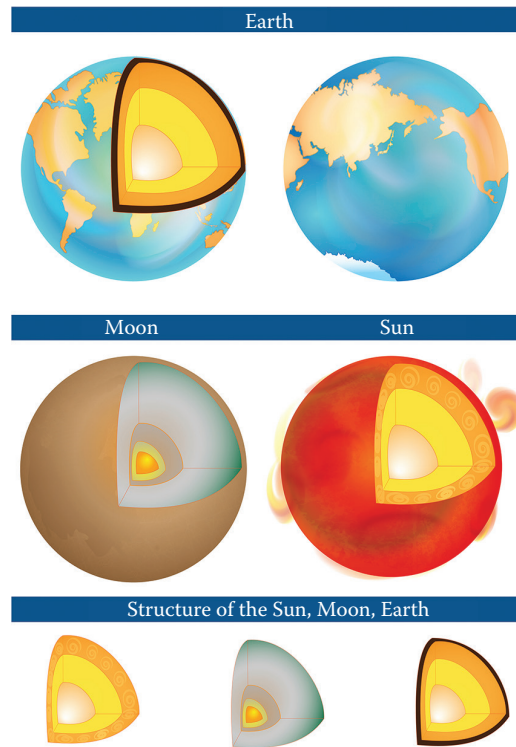


Figure P.78 Layers of the Sun, outlining the photosphere.

Photosynthesis

[biomedical, geophysics, thermodynamics] The phenomenon of the conversion of carbon dioxide to oxygen by plants as postulated in 1779 by a scientist from the Netherlands: JAN INGENHOUSZ (1730–1779).

Even though the discovery of the molecule oxygen (O_2) was only recent in these days of discovery in 1774, by JOSEPH PRIESTLEY (1733–1804) (see [Figure P.79](#)).

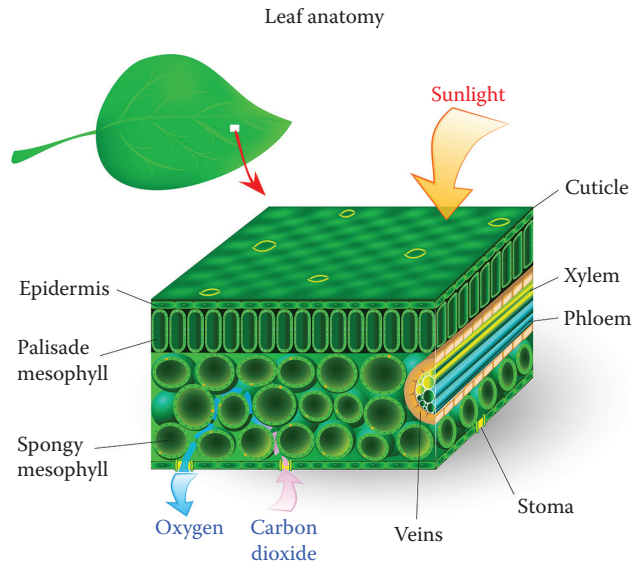


Figure P.79 Process of photosynthesis, primarily known for its action through the chloroplasts in the leaves of plants; however, the skin of various mammals also has photosynthesis capabilities. The skin photosynthesis also produces a necessary hormone and chemical catalyst for cellular function: vitamin D, in addition to a rudimentary supply of oxygen. During exposure to sunlight, high-energy ultraviolet light (specifically in the range 290–315 nm) is absorbed in melanin that is part of the tissue structure directly underneath the epidermis of the skin and the photon energy is used to photolyze provitamin D3 (7-dehydrocholesterol) to previtamin D3. Once previtamin D3 is formed, it undergoes an isomerization process that is thermally induced and forms vitamin D3. The isomerization process takes 2–3 days to reach completion. Additionally, certain algae and seaweed and certain organisms, such as the *Euglena* species (found in both fresh- and saltwater), also provide a significant contribution to the conversion of carbon dioxide into oxygen. Some scientists claim that algae and seaweed combined provide the lion's share of oxygen production, exceeding that of surface plants. The true respective contributions remain difficult to quantify accurately due to a broad range of ill-defined and transient boundary conditions.

Phototoxicity

[biomedical, chemical, optics] Inflammatory toxic response, primarily associated with the SKIN, under the influence of LIGHT exposure of surface areas that have been in contact with certain chemicals. Phototoxicity may sometimes be misdiagnosed as sunburn but is a different dermal response on a chemical and cellular level.

Photovoltaic effect

[atomic, nuclear] Electric current generated as the result of light irradiance of a junction between two media of different chemical composition in direct contact. The effect was first observed by ANTOINE HENRI BECQUEREL (1852–1908) in 1839. The photovoltaic effect can also be applied in combination with an externally induced potential difference (V), providing a CURRENT (I) as a function of the irradiance (I_{rad}) and temperature at the junction (T): $I = I_{\text{reverse}} \{ \exp(eV/kT) - 1 \} - I_{\text{rad}}$, where $e = 1.60217657 \times 10^{-19} \text{ C}$ is the

electron charge and $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ is the BOLTZMANN CONSTANT (*also PHOTOVOLTAICS or PHOTOELECTRIC EFFECT*) (see [Figure P.80](#)).

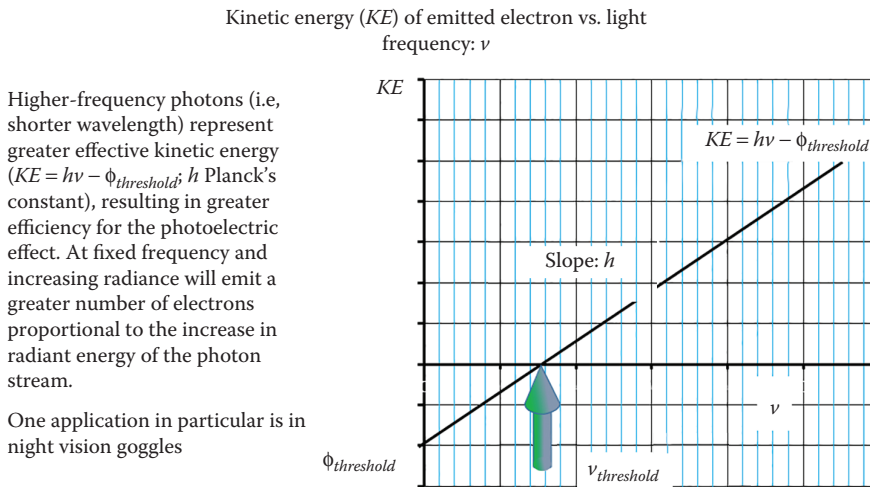


Figure P.80 Graphic representation of the photovoltaic effect.

Physics

[general] (Ancient Greek: φύσις physis “nature;” the Knowledge of Nature, in principle the knowledge of how things work and how phenomena originate. Latin: physica, plural, “natural science”) A natural science that involves the study of MATTER, phenomena, the MOTION of object and phenomena through both space and time, as well as all related force and ENERGY concepts. More broadly, the general hypothetical description and analysis of nature, with associated laws of conservation and rules and laws of conduct. The study of physics postulates rules about the conduct of events and phenomena in order to understand, and predict how the UNIVERSE behaves and how matter and energy interact. Most laws and definitions in physics are proven within certain boundary conditions and are correct until new observations require adjustments to the theory, one example is the special relativity concepts, following classical Newtonian physics. The first known use of the “physics concept” was 1715. The broad spectrum of physics has been further subdivided into the following topics: classical, high energy, nuclear, relativistic, THERMODYNAMICS, FLUID DYNAMICS, hydrodynamics, fluid mechanics, dynamics, statics, MECHANICS, OPTICS, photonics, QUANTUM MECHANICS, electromagnetism, BIOPHYSICS, theoretical physics, GEOPHYSICS, ASTROPHYSICS, ACOUSTICS, high-pressure, low-temperature, PLASMA physics, particle physics, and many new subdisciplines being demarcated on a continual basis. The list of areas of interest in physics is not intended to be all encompassing, various topics

will overlap between the nomenclature and also depend on the respective execution-group interests (see Figure P.81).

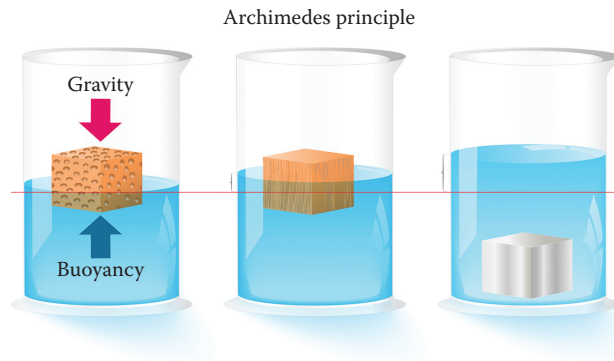


Figure P.81 Physics as a technology platform.

Physics constants

[general] Broad range of constants used in the various definitions within the integral field of PHYSICS, ranging from the electron charge to the speed of LIGHT, found in many description throughout the encyclopedia.

Physics laws

See LAWS OF PHYSICS.

Physiologic dead space

[biomedical, fluid dynamics] Physiologic dead space is defined as the volume of expired AIR per breath that does not receive any CO₂ from the BLOOD flow through that part of the lung. In RESPIRATION, the volume capacity of the lung is measured using this as one of the characteristics for the individual examined.

Physiologic dead space quantifies the volume of the trachea, bronchi, and bronchioles, which is not involved in the exchange of oxygen with blood (i.e., anatomic dead space), in addition to the volume of “damaged” alveoli that have vascular constraints that limit the blood flow and hence limit the exchange of oxygen with blood (i.e., alveolar dead space). The method specifically determines the physiological dead space of the lung total expired volume. In certain regions of the lung, there can be a very high ventilation-to-perfusion ratio, with an associated wasted VENTILATION, which acts as physiologic dead space.

Physiologic dead space can be measured using the Bohr method. The Bohr method collects all expired air is over several breaths. The expired partial pressure for those breaths (P_{ECO_2}) is measured. Concurrently, a sample of alveolar air (i.e., end-tidal air; with volume V_t) is collected, the air that is exiting at the end of expiration during forced expiration. This end-tidal air does not contain a significant amount of dead space air, hence serves as a representative of alveolar air. From the end-tidal breath, the alveolar P_{ACO_2} is measured. The total expired CO₂ per breath is by definition from the expired alveolar air. Dead space volume (V_d) can be

derived from the fact that the total amount is concentration multiplied by volume:

$V_a/V_t = (P_{aCO_2} - P_{CO_2})/P_{aCO_2}$ (Bohr equation; defined by the Danish physician CHRISTIAN BOHR [1855–1911]) (see Figure P.82).

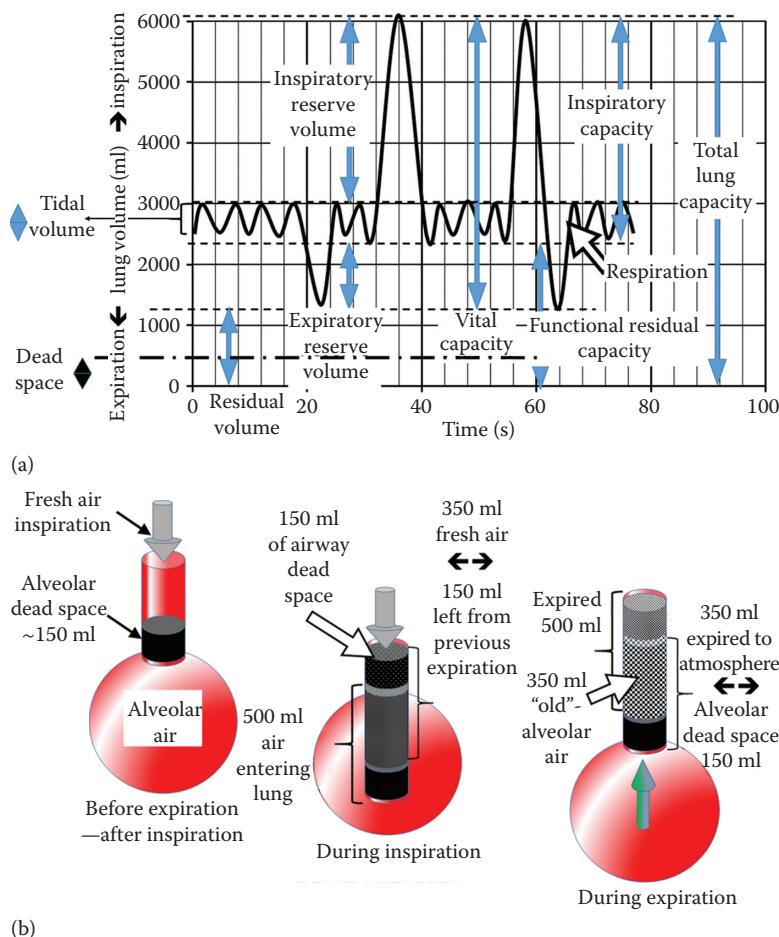


Figure P.82 Physiologic dead space in the process of respiration. (a) Normal respiration and (b) volume diagram for the lungs.

Physiology

[biomedical, chemical, general] Study of the activities involved in biological entities. Description and QUANTIFICATION of the operational functionality of organs, cells as well as on a molecular level, including enzyme interactions and hormones. A general study of how biological organism function, with associated ENERGY, balances and ENGINEERING interactions. The first recorded principles of physiology date back to

HIPPOCRATES (approximately 470–377 BC) in 420 BC, hence known as the father of modern MEDICINE (see Figure P.83).



Figure P.83 Brain regulating the activities of a person that is performing an activity and hence has cells that perform a physiological activity.

Physisorption

[atomic, biomedical, energy, thermodynamics] The process of electron interaction on a Van der Waals attraction level, describing the ADSORPTION while the electron structure remains unaffected. The adsorption process refers to the chemical hybridization of electrons in a molecular surface. The electrons in orbit can be considered electron clouds. In contrast during chemisorption the electrons are affected, performing a perturbation of the chemical bonds. Under helium beam interaction with helium the SCATTERING process is described as physisorption with very low ENERGY content (order of meV).

Piano

[acoustics, computational] Acoustical string instrument used to produce music by tapping strings with blocks attached to the keys on the front of the instrument. There are two particular kinds of pianos: upright and grand-piano. The grand piano has gained popularity from the manufacturer Steinway for over 160 years. The history of the piano dates back to the harpsichord of the beginning of the eighteenth century, evolving to the pianoforte. The Harpsichord was invented by the Italian musician and craftsman Bartolomeo Cristoforo (1655–1731). This was the equivalent of what is now known as the “grand piano.” The composer Beethoven was writing music for the piano when the instrument was close to one hundred years old. The upright piano was designed in 1780 by the Austrian Johann Schmidt (late eighteenth century). The “hammer” design of the piano creates a SOUND by actuating the string in a time segment of milliseconds, the duration will largely depend on the force with which the key stroke is played. The key stroke affects the harmonic spectrum of the string as well as the LOUDNESS. The tone spectrum of the piano generally covers better than six octaves, ranging approximately from 25.5 to 4186 Hz for the fundamental frequencies with harmonics spanning from 2 to 12 kHz. The sound spectrum is influenced by the string

material, the string tension as well as the reverberations in the mechanical device housing the strings, with its inherent material properties and stresses and strains (see [Figure P.84](#)).



Figure P.84 Grand piano.

Picard, Jean-Félix (1620–1682)

[astronomy] French astronomer. He equipped a TELESCOPE with Vernier-type gauge lines that could be used for MEASUREMENT and laid the foundation for angular division of the globe in longitude and latitude scales for cartography.

Pickering, Edward Charles (1846–1919)

[astrophysics/astronomy, atomic] Physicist and astronomer from the United States. He is best known for his derivation of the spectral line series: PICKERING SERIES (see [Figure P.85](#)).



Figure P.85 Edward Charles Pickering (1846–1919) by Sarah Goolll Putnam (1851–1912). (Courtesy of Harvard University Portrait Collection.)

Pickering series

[atomic, nuclear] Helium absorption lines for helium found in hot stars. The Pickering lines are for a special IONIZATION state of helium (He^+ , singly ionized, instead of He^{2+}) involving a transition to the $n = 4$ QUANTUM STATE. The Pickering lines closely resemble the transition lines for the BALMER SERIES to the $n = 2$ quantum state.

Pickup reaction

[nuclear] The reverse of a single NUCLEON transfer reaction, in this case a nucleon is removed from the target NUCLEUS.

Picture

[general] Two-dimensional IMAGE captured on a canvas (painting), paper (drawing), digital array, or on PHOTOGRAPHIC PLATE (photographic film), representing a visual PERCEPTION of an object or event. Photographic film, or digital array (digital CAMERA) is the prominent mechanism for capturing a picture and preserving the experience for posterity. In digital image capture, the picture ELEMENTS are referred to as pixels, the individual array elements with the gray-scale respectively COLOR coding information of one location in the total reconstituted display (see [Figure P.86](#)).

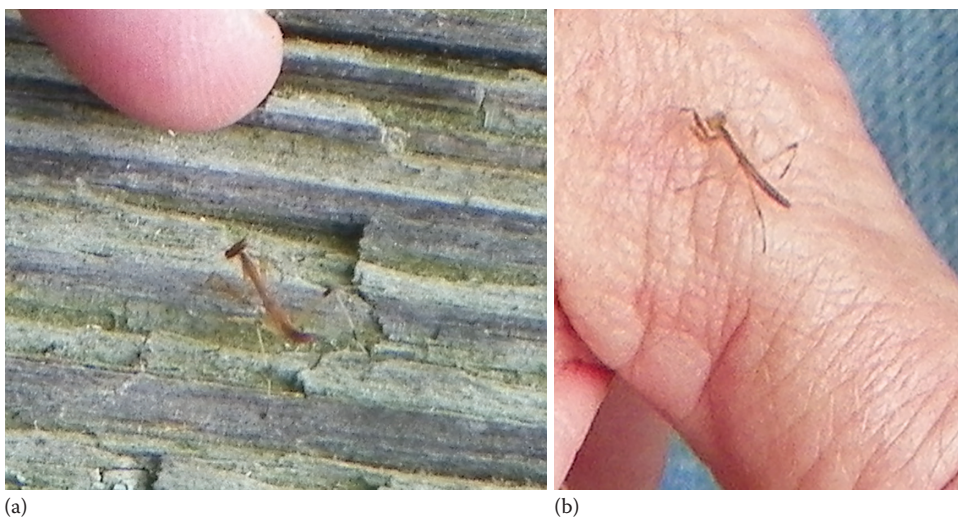


Figure P.86 (a,b) Picture of baby “praying mantis” (“walking stick,” since it resembles a tiny branch), insect: *Carausius morosus* of the order Phasmatodea. The population consists virtually exclusively of females. The females are able to lay fertile eggs, without the requirement of mating or for that matter the presence of males. The eggs hatch and also develop into females.

Piezoelectric effect

[acoustics, atomic, energy, fluid dynamics, general, mechanics, quantum] Electromechanical process (i.e., strain) in certain materials. The materials that can produce this effect have specific symmetry features, LATTICE structure related for instance. Additional effects producing the piezoelectric effect include the stress induced in a material by an applied electric field. The piezoelectric effect was discovered in 1880 by PAUL-JACQUES CURIE (1856–1941) and PIERRE CURIE (1859–1906). Example materials that possess the piezoelectric effect are quartz, ferroelectric ceramics, and certain salts. Rochelle SALT (potassium sodium tartrate: $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ first known preparation in the late 1600s by Pierre Seignette (1660–1719), an apothecary of La Rochelle, France; used as a laxative); discovered to have pyroelectric properties by SIR DAVID BREWSTER (1781–1868) in 1824 later to show piezoelectric properties by the Curie brothers.

One specific example of the practical use of the piezoelectric effect is in a quartz-based timing mechanism used in clocks, a battery-operated quartz resonator (*also see* ULTRASOUND) (see [Figure P.87](#)).



Figure P.87 Piezoelectric effect applied for ignition of a gas stove-top flame.

Piezoelectric resonance

[acoustics, atomic, electromagnetism, fluid dynamics, general, mechanics, quantum] Certain materials will develop mechanical stress under the influence of electrical voltage. The crystal structure is polarized by the external application of the potential difference creating an electrical DIPOLE. The crystal will have one dominant axis of mechanical ACTIVITY. The process can also be reversed, where mechanical stress will provide an electrical potential across the crystal proportional to the MAGNITUDE of the applied stress. The electronic OSCILLATION results from the electronic configuration as described under oscillation, with a frequency: $\nu = 1/2\pi\sqrt{LC}$ and this frequency will ideally match the mechanical boundary conditions with resonance frequency: $\nu_r = 1/2\ell_1\sqrt{\rho s_{11}^E}$, where ℓ_1 is the fundamental length of compression (generally, the crystal will have three sides: $\ell_1 > \ell_2 > \ell_3$), ρ is the material density of the piezoelectric crystal, and s_{11}^E is the elastic COMPLIANCE under a constant electric field resulting from a constant electrical potential. Under ideal conditions the mechanical and electronic RESONANCE FREQUENCY will be match for optimal ENERGY conversion. Piezoelectric resonance can for instance be used in tweeter speakers for high-frequency acoustic SOUND emission (*also see* OSCILLATION and RESONANCE) (see [Figure P.88](#)).



Figure P.88 Tweeter with piezoelectric resonance-driven transverse wave emission.

Piezoelectric transducer

[acoustics, atomic, energy, fluid dynamics, general, mechanics, quantum] Around 1880 **PIERRE CURIE** (1859–1906) and **PAUL-JACQUES CURIE** (1856–1941) discover the electromechanical properties of specific ceramic crystals. One of the best known crystals is PZT: lead (Pb) zirconate (Zr) titanate (Ti): $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$, oxygen (O), a ceramic perovskite (see [Figure P.89](#)).

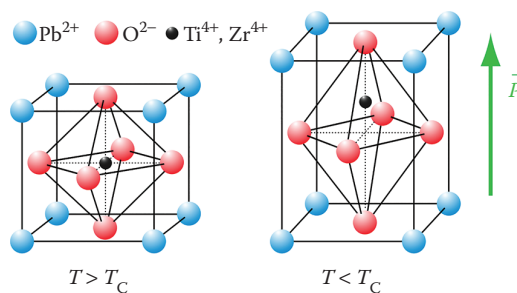


Figure P.89 Chemical structure of ceramic PZT crystal: $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$.

Piezoelectricity

[acoustics, atomic, energy, fluid dynamics, general, mechanics, quantum] The mechanism providing the means of transferring stress and strain into electrical SIGNAL, reversible electromagnetic process. Applying an electrical potential to certain materials will deform the material. Piezoelectricity is applied for microphones, pressure transducers, and ULTRASONIC IMAGING devices (both as source and detector) (*also see* **PIEZOELECTRIC EFFECT**).

Pinch effect

[atomic, nuclear] **PLASMA** effect that constricts the electric current due to the narrowing of an electric field, causing the charges to increase per cross-sectional area representative of the kinks in sausage links. Lightning bolts are a visual example of pinched plasma filaments. The pinch effect can also occur in liquid **CONDUCTOR** (LIQUID metal) or solid conductors. The process is the result of **MAGNETIC FIELD** lines. Experimentally the pinch effect is produced in Tokamak systems (plasma) with respect to **NUCLEAR FUSION** (see [Figure P.90](#)).

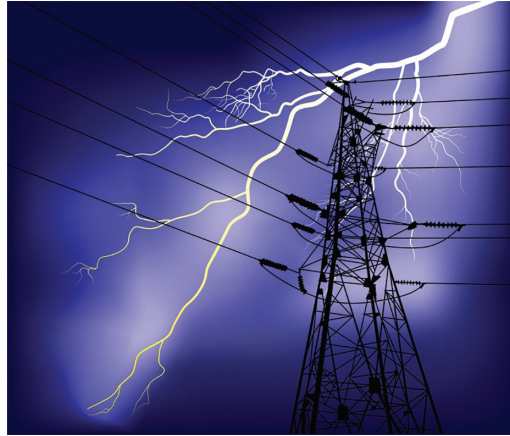


Figure P.90 Lightning “pinch.”

Pinch temperature

[thermodynamics] Smallest temperature difference in a steam **TURBINE** between the temperature profile for **AIR** and water, analytically equivalent to the smallest temperature difference between the cold curve and the hot curve (e.g., steam) for a heat-exchange process. The heating medium can be of any kind: **GAS** (propane, methane, etc.), gasoline, electric, coal and so forth (see [Figure P.91](#)).

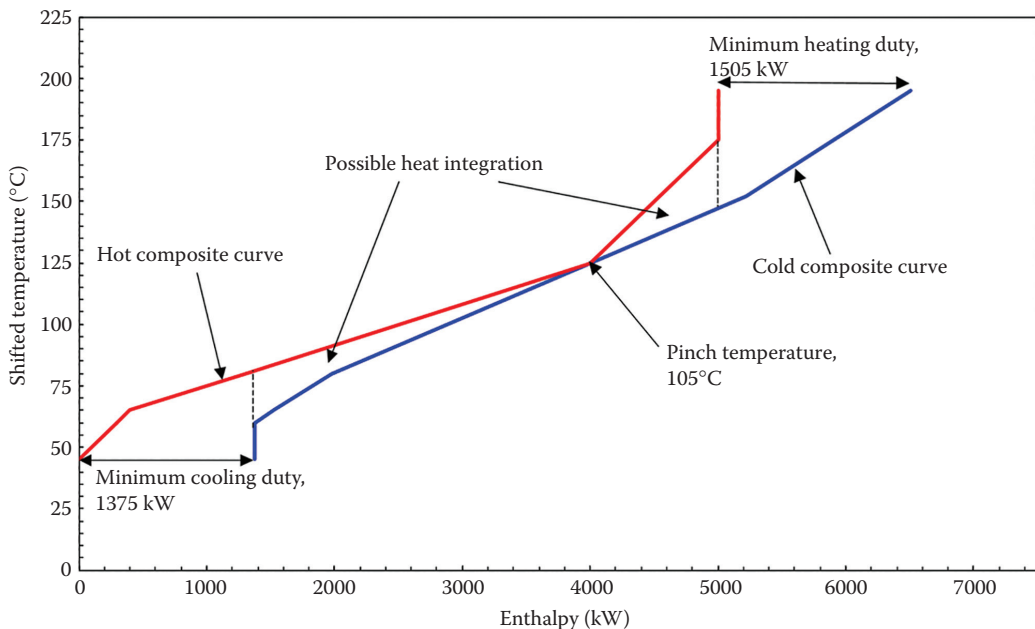


Figure P.91 Pinch temperature in a heat exchanger between hot steam and cold steam.

Pinocytosis

[biomedical] The active process of LIQUID transport from the outside of the CELL MEMBRANE to the interior of the CELL by means of the formation of a vesicle. This process is part of cellular ingestion classified as ENDOCYTOSIS, which also includes solid consumption defined as PHAGOCYTOSIS. On the MECHANICS of the selective restructuring of the lipid-protein bilayer (*also see* CELL MEMBRANE) (see [Figure P.92](#)).

Role of an antigen-presenting cell

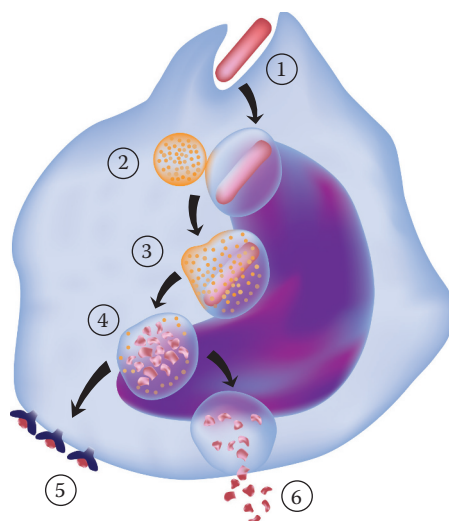


Figure P.92 Pinocytosis, would be similar to phagocytosis except for the cell consumption is liquid instead of solids. (1) Phagocytosis of enemy cell (antigen); (2) Fusion of lysosome and phagosome; (3) Enzymes start to degrade enemy cell; (4) Enemy cell broken into small fragments; (5) Fragments of antigen presented on APC surface; (6) Leftover fragments released by exocytosis.

Pion

[astrophysics/astronomy, atomic, energy, general, nuclear, quantum, thermodynamics] Elementary PARTICLE in the category of MESON. The pion was discovered in 1947, and has a mass equivalent ENERGY of $E = mc^2 = 135 \text{ MeV}$ (*also see* PI-MESON).

Pipe

[computational, fluid dynamics] Fluid conduit. Flow in pipes will generally obey the Bernoulli equation and Poiseuille's equations. Pipes will provide LAMINAR FLOW under steady state relatively low flow velocity. A straight pipe with uniform diameter has no particular geometric configurations that will provide conditions that are conducive for flow other than laminar. Junctions connecting pipes with different diameters or pipes with curvature will however provide the boundary conditions that can result in turbulent flow. Computational FLUID DYNAMICS will describe the flow in curved pipes with discrete or continuous changes in diameter due to the complex nature of the boundary conditions as a function of axial and radial location. Pulsatile flow will generate complex conditions that are not easily solved by analog means and will require in-depth computational simulation. Compliant pipe describes the flow in BLOOD vessels and has time-dependent boundary conditions and well as involves PULSATILE FLOW. For a flexible tube, the COMPLIANCE is defined as $C_{\text{compliance}} = \partial A / \partial P$, where A is the cross-sectional area of the tube and P the local pressure; this translates into a distensibility: $D_{\text{dist}} = (1/A)(\partial A / \partial P) \xrightarrow{\text{thin wall}} (2r/d)[(1 - \nu_p^2)/Y_n]$, with Y_n the Young's modulus of the tube material, ν_p the Poisson ratio, r the tube radius, and d the wall thickness. The flow (Q) in the flexible tube is approximated by the "windkessel" model as $Q = C_{\text{compliance}} (\partial P / \partial t) + (P / R_p)$, where R_p represents the peripheral RESISTANCE and t is time. This can be

developed in a FOURIER SERIES for pulsatile flow with ANGULAR FREQUENCY $\omega = 2\pi\nu$, ν the frequency: $\hat{Q} = [i\omega C_{\text{compliance}} + (1/R_p)]\hat{P}$. Because of the BOUNDARY LAYER the flow at the wall is generally stagnant and the material transport close to the boundary can be discarded by rejecting the boundary flow by applying an ORIFICE (syphoning off the boundary layer; for instance applied to transcontinental FLUID transportations). This way the flow medium may be changed but the output consistency can be pure and consistent at the core (see Figure P.93).



Figure P.93 Pipe.

P

Pipeline parameter ($\rho^n = \omega_{gr}\omega_0/2gH$)

[fluid dynamics, mechanics] Dimensionless number used in MOMENTUM transfer associated with the WATER-HAMMER phenomenon, where v_{gr} is the GROUP VELOCITY of the WAVE phenomenon, v_0 is the initial VELOCITY, g is the GRAVITATIONAL ACCELERATION, H is the STATIC HEAD. One area of interest in this is for mining and OIL drilling with regard to slurry and oil transportation. The pipeline parameter provides a metric for the hydraulic characteristics of a flow system. For instance, a value of $\rho^n > 1$ may require the use of a reflux VALVE bypassing the system's PUMP. The pipeline parameter is a means of predicting problematic circumstances and safety concerns.

Pitch

[general] Human perceptual response to frequency of acoustic ENERGY, a bass is low pitch and a flute has a high pitch. Pitch is primarily associated with the zero-order harmonic of the instrument or source of the SOUND. A related expression is from the French word "TIMBRE." The timbre denotes the base frequency as well as the spectrum, the "COLOR" of the sound of the device producing the sound (see FREQUENCY and WAVELENGTH) (see Figure P.94).



Figure P.94 French horn emitting a “rainbow” of sound i.e. frequency spectrum; analogous to an optical spectrum.

Pitot, Henri (1695–1771)

[fluid dynamics] Scientist and hydraulic engineer from France. The PITOT TUBE for measuring flow velocity was named after him. He also gained fame for the design of the aqueduct in Montpellier, France; the aqueduct saint Clément de Montpellier also called the aqueduct Pitot (see [Figure P.95](#)).



Figure P.95 Henri Pitot (1695–1771).

Pitot theorem

[computational] The opposite sides of a quadrilateral (four-sided closed outline of regular or irregular shape; special case rectangle) enclosing a circle are equal to the sum of the remaining sides: $AB + CD = BC + DA$. Proposed by the French engineer and mathematician HENRI PITOT (1695–1771) in 1725 (see [Figure P.96](#)).

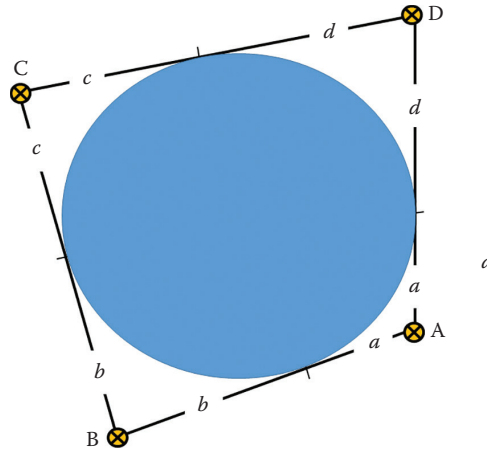


Figure P.96 Pitot theorem.

Pitot tube

[fluid dynamics] Tube invented by the French scientist and engineer HENRI PITOT (1695–1771), later modified by the French engineer Henry Darcy (1803–1858) and is widely used to measure flow velocity, specifically for airflow around the WING of a plane or water flow speed for a boat as well as TURBINE generators/engines. The Pitot tube is relatively narrow, open on one side, facing upstream and is connected to a MANOMETER on the opposite side, providing the stagnation pressure (P_t) also referred to as the total pressure. The principle relies on Bernoulli's theorem. In a modified form, the static pressure (P_s) is measured by placing small perforations in the WALL of the tube. The flow velocity (v) is defined as $v = \sqrt{\{2(P_t - P_s) / \rho\}}$, where ρ is the density of the flow medium. The flow velocity is an indirect means of determining the velocity of the craft. Ice formation in the Pitot tube could have been the cause of several airplane accidents in the past, and nowadays it is hence heated (see [Figure P.97](#)).



Figure P.97 Pitot tube on the nose of the plane.

Pixel

[imaging, theoretical] Smallest unit area on sensor array with uniform intensity of all spectral lines due to the fact that it is a self-confined single ELEMENT as part of a larger detector or display raster assembly. Generally, the pixel is part of a two-dimensional arrangement, forming a component of an IMAGE: a picture element. Pixels are describing the sensor ELEMENTS of a CAMERA as well as the display elements of a screen. The sensing elements can be components of a CCD CAMERA, alternatively the RGB-LED (red-green-blue–light emitting diodes) clusters or LCD (LIQUID crystal display) sections on a visual display unit (see [Figure P.98](#)).

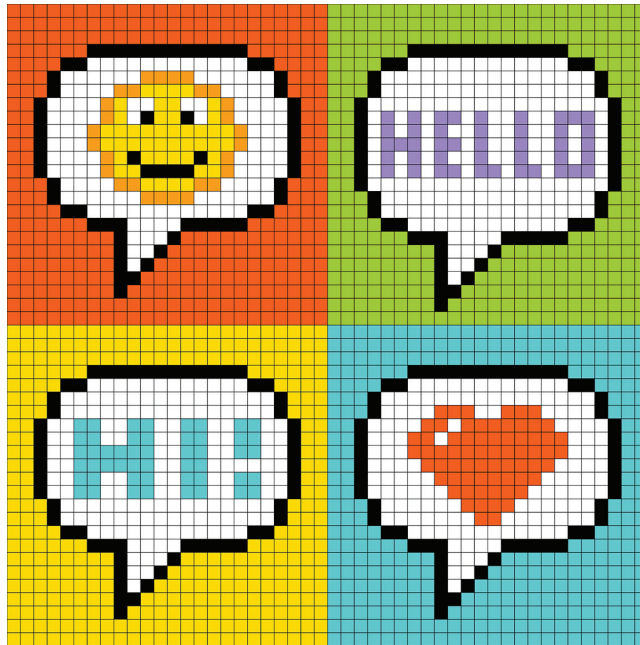


Figure P.98 Images constructed for low-resolution pixels, each individual single-colored square.

Planck, Maxwell Karl Ernst Ludwig (1858–1947)

[atomic, computational, energy, general, nuclear, thermodynamics] German scientist. Introducer of the concept of QUANTUM THEORY in 1900. The theoretical concept of the fact that ELECTROMAGNETIC

RADIATION has a discrete ENERGY SPECTRUM was derived from Planck's experimental and theoretical work on BLACK-BODY RADIATION. In 1905, ALBERT EINSTEIN (1879–1955) substantiated the work of Max Planck by his introduction of the PHOTON-PARTICLE DUALITY theory (see [Figure P.99](#)).

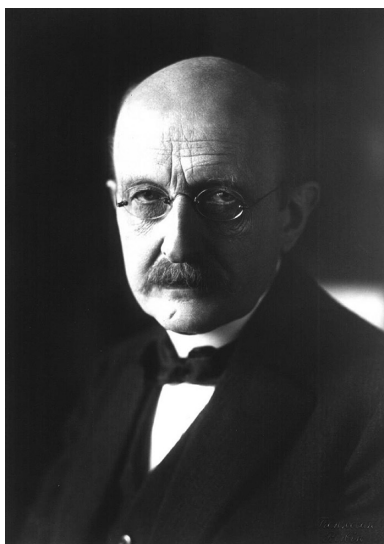


Figure P.99 Maxwell Karl Ernst Ludwig Planck (1858–1947).

Planck's Constant h

[atomic, computational, electromagnetism, energy] A natural constant of proportionality relating the frequency of a quantum of ENERGY to the total energy of the QUANTUM, $h = 4.1356692 \times 10^{-15}$ Js. Often the derived Planck's constant "h-bar:" $\hbar = h/2\pi$, introduced by PAUL ADRIEN MAURICE DIRAC (1902–1984) is used in simplified equation format.

P

Planck's law

[atomic, nuclear] See **PLANCK'S RADIATION LAW**.

Planck's radiation law

[atomic, nuclear] Black-body RADIATION spectral definition by MAX PLANCK (1858–1947) in response to a challenge by Kirchhoff in follow-up on the Kirchhoff radiation law: $\epsilon_\lambda/\alpha_\lambda = I_\lambda$, where ϵ_λ represents the radiated ENERGY as a function of the wavelength (λ), α_λ the fraction of absorbed energy, and I_λ the energy incident on the "black-body." Combining this with the WIEN'S DISPLACEMENT LAW and the energy (E) quantization: $E = h\nu$, with $h = 4.1356692 \times 10^{-15}$ Js the PLANCK CONSTANT, and $\nu = c/\lambda$ the frequency

(c the speed of light). This led Planck to derive the spectral energy distribution: $I_\lambda = 2\pi hc^2/\lambda^5 \left(e^{hc/\lambda k_B T} - 1 \right)^{-1}$, with $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ Boltzmann's constant, and T temperature (see [Figure P.100](#)).

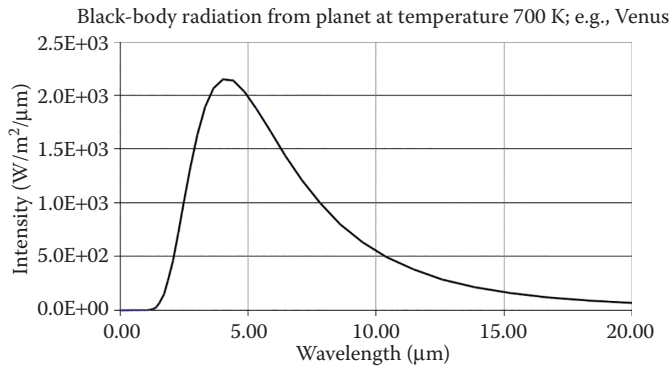


Figure P.100 Planck's radiation law.

Plane of incidence

[general] The local surface area with the normal vector indicating the largest congruent area with equal vector representation. The plane of incidence makes an ANGLE with the vector of the direction of propagation of the incident ENERGY form (PARTICLE OR WAVE).

Plane of polarization

[general] The plane in which the direction of the electric field of ELECTROMAGNETIC RADIATION is directed (see POLARIZATION) (see [Figure P.101](#)).



Figure P.101 The light reflected from the seawater is polarized in the horizontal direction, which is suppressed when viewing through the polarizer filter, reducing the glare.

Plane wave

[general, optics] $U(\vec{r}) = \mathcal{A}e^{ik\vec{r}}$, where $k = 2\pi/\lambda$ is the wavenumber, $\vec{r}$ the vectorial DISTANCE to the source, and $\mathcal{A}$ a constant (i.e., AMPLITUDE). The plane wave SOLUTION follows from the Euler theorem.

Plane-polarized waves

[general] ELECTROMAGNETIC RADIATION with the electric field in a fixed single direction. Generally, ordinary light-sources emit unpolarized light, with POLARIZATION direction that is continually changing with no fixed pattern of direction, or for a single time frame, the LIGHT will be a combination of photons that form a ray that can be considered to consist of elliptically (circularly) polarized light with a random combination of electric field directions (see [Figure P.102](#)).

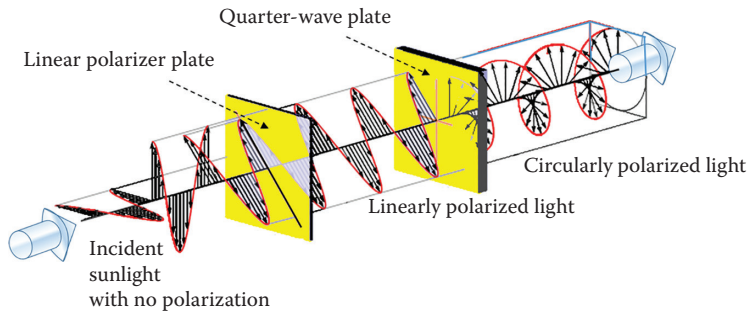


Figure P.102 Plane wave.

Planet

[general] In general, galactic material in our SOLAR SYSTEM has to satisfy the following three criteria in order to classify as planets: (1) the material needs to orbit around the SUN in a regular pattern, (2) the material needs to have enough mass to generate a cohesive gravitational force that constrains the orbiting mass into a spherical geometry, and (3) the mass in orbit needs to be cohesive, collecting all mass in the same orbiting pattern (i.e., no debris in the same path), as defined by the International Astronomical Union (IAU). As a result Pluto was recently discarded as a qualified planet leaving only 8 planets in our Solar system; from the Sun outward: Mercury, VENUS, EARTH, MARS, JUPITER, SATURN, Uranus, and Neptune. Two additional dwarf planets at the outer edge of our Solar system have been recognized in orbit but with debris: Pluto and Eris, where Eris and Pluto are relatively close and Eris was discovered fairly recently. The ASTEROID Ceres also meets those requirements postulated by the IAU and hence is a dwarf planet as well (see [Figure P.103](#)).

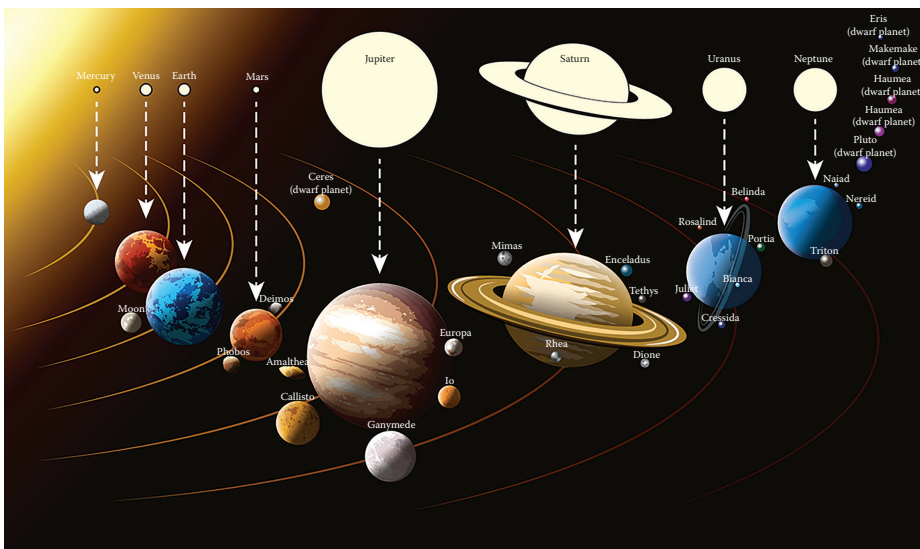


Figure P.103 Planets.

Planetary data

[astrophysics/astronomy, computational] The SOLAR SYSTEM consists of the SUN in the center with planets orbiting around it from the inside to the outside, conventionally: Mercury, VENUS, EARTH, MARS, JUPITER, SATURN, Uranus, Neptune and Pluto; with Jupiter the largest (about 11 times the diameter of Earth). However, certain philosophies are considering Pluto to be a dwarf PLANET (size one-fifth the diameter of Earth, our MOON has a diameter that is one quarter of Earth's diameter on average) and may not be counted as a full planet, making Neptune the outermost planet. Most recently another planet (dwarf) at the outer extremity has been added, for instance Eris. Additionally, Pluto has a substantial size moon: Charon, which makes the orbit of Pluto go inside the orbit of Neptune for nearly 20 years (total solar orbit 248 earth-years). Pluto's moon, Charon, makes it a double planet. Pluto has a total of three moons, two of which very small (*also see SOLAR SYSTEM, and respective planets*) (see [Figure P.104](#)).

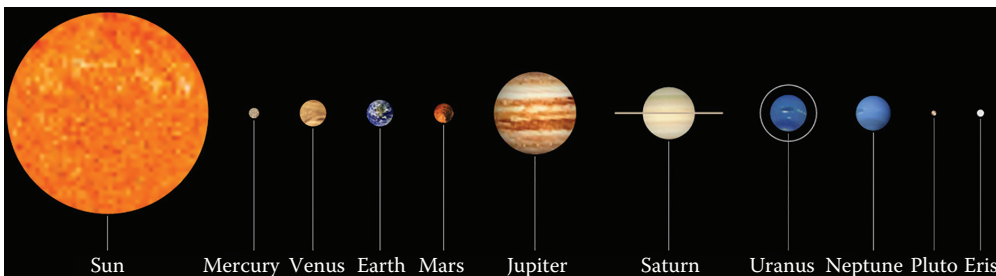


Figure P.104 Planetary system and galactic objects.

Planetary motion

[astrophysics/astronomy, general, geophysics] The planets in orbit around the SUN primary are responding to the gravitational attraction by the Sun, which represents 99.9% of all the mass in our SOLAR SYSTEM. The orbiting planets do however influence the ORBITS of neighboring planets under a perturbation effect, making the orbits deviate from the perfect ellipsoidal pattern. The orbital velocity (v_o) of each planets results in first-order approximation on the CENTRIPETAL FORCE balancing the gravitational force: $v_o = \sqrt{(GM_{\text{sun}}/r)}$, where G is the gravitational constant, M_{sun} the mass of the Sun, and r the respective planetary DISTANCE to the Sun. Please note that the orbits are not perfectly circular (*see KEPLER'S LAW*) (see [Figure P.105](#)).

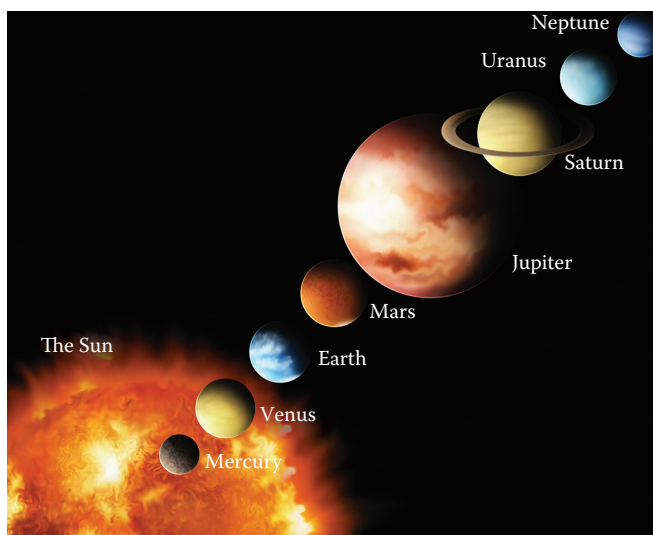


Figure P.105 Graphical representation of the relative size within our Solar system.

Planetary motion, Kepler's laws of

[astronomy/astrophysics, general, geophysics] See **KEPLER'S LAWS**.

Planetary orbits

[computational, geophysics] See **KEPLER'S LAW**, as described by **JOHANNES KEPLER** (1571–1630).

Planetary precession

[astrophysics/astronomy, general, geophysics] Precession of a planet's **SPIN** axis, in addition to the “wobble” of the Earth's axis every 26 000 years. For the **EARTH**, the precession angular tilt (ϕ) with respect to the normal to the **INVARIABLE PLANE** (the Laplace plane), which is inclined to the planetary equator by ϑ . The spatial orientation of the planetary orbit can be described by the **EULER ANGLES** for the ecliptic and **EQUINOX** position (respectively: φ, ω, Ω). This **PRECESSION** can be described under the assumption that the variations induced by the **MOTION** resulting from the **SUN** and its own satellites (planetary perturbations, as well as our own **MOON**) is given as $\partial\phi/\partial t = -(3/2)(MR_e^2/I_c\omega_s)J_n n^2 \{\cos\epsilon_e + \sum_j [(n_j/n)^2 [M_j/(M_j + M)] \cos(\epsilon_e - \vartheta_j)]\}$, where M is the mass of the **PLANET** in precession, R_e is the planetary radius, J_n are harmonic coefficients (also referred to as zonal coefficients; derived from the Legendre polynomials [Legendre functions: P_{nj} ; for instance, $P_{00} = 1$, $P_{10} = x$, $P_{20} = (3x^2 - 1)/2$, etc.]), ω_s is the angular spin of the planet, I_c is the moment of **INERTIA** for the polar axis, M_j is the mass of adjacent planets and satellites (**SATELLITE** is a term introduced by **JOHANNES KEPLER** [1571–1630]), $n = d/dt(\varphi + \omega + \Omega)$ is the orbital mean displacement motion for the planet with respect to the Sun, and ϵ_e is the inclination of the equator with respect to its orbit. Note that the seasons on Earth are the result of the orbital position of the Earth with respect to the Sun and the **ANGLE** of the Earth's axis in the rotational plane creating the seasons: summer, autumn, winter, and spring. The presumably fixed angle of the Earth's axis in the solar orbit is however affected by the Earth's precession and will cause the seasons to shift.

Planetary vorticity

[dynamics, general, geophysics] See **CORIOLIS FREQUENCY**.

P

Plasma

[atomic, biomedical, general, nuclear] One of the four states: solid, **LIQUID**, vapor/gas, and plasma. A plasma is a condition of a medium where the electrons of a significant number of atoms have been removed and flow freely, mixture of atoms, ions, and electron clouds, existing predominantly at high temperature, however, with a high density that does not correspond to the otherwise “gaseous” behavior of the plasma medium. Plasma generally has a luminous behavior, for instance a sodium lamp, fluorescent lamp, or “neon” lamp are plasma **LIGHT** sources. The **SUN** is also a plasma as well as a **NUCLEAR FUSION** reactor. Additionally, **BLOOD** is composed of plasma as the main fluid, with red and white blood cells and dissolved proteins, next to **GLUCOSE**, clotting factor (providing the means to congeal/coagulate blood—forming a

“scab;” also provides the mechanism to form blood clots [thrombus]) and electrolytes, dissolved carbon dioxide (carbolic ACID) and hormones and enzymes and more (see [Figure P.106](#)).



Figure P.106 Plasma.

Plasma frequency

[atomic, nuclear] Oscillations within a PLASMA resulting from the electron thermal velocity (v_e). The wavelength of the OSCILLATION (λ_D) has the Debye length $\lambda_D = v_e / 2\pi v_{pe}$, with frequency dominated by the free electron density (n_e): $v_{pe} = \omega / 2\pi = \sqrt{(n_e e / \pi m_e)} = 8.97 \sqrt{n_e}$ Hz, where m_e is the electron mass and e is the electron charge. The plasma oscillation phenomenon was observed by the American chemist and physicist IRVING LANGMUIR (1881–1957) in 1929.

Plasmon

[atomic, nuclear] Quantum of OSCILLATION energy in a PLASMA, defined as $E_{pl} = \hbar \sqrt{(4\pi n_e e^2 / m_e)}$, with $\hbar = h / 2\pi$ ($h = 4.1356692 \times 10^{-15}$ J s the PLANCK'S CONSTANT), n_e the free electron density, m_e the electron mass, and e the electron charge.

Plastic strain

[geophysics, mechanics] Permanent deformation in shape or size of an entity without resulting in destructive fracture, which may accumulate over time as the result of a sustained stress that exceeds the elastic yield point for the constitution of the material. Plastic strain can be expressed as a POWER LAW defined as the strain rate ($\dot{\epsilon}_s = \dot{\epsilon}_s$), linking applied stress (σ_s) to the activation ENERGY for deformation (Q_{ac}), the prevalent temperature (T) as $\dot{\epsilon}_s = A\sigma_s^n \exp(-Q_{ac}/RT)$, where n is the heuristic power function constant, which is derived from experimental data, A is an arbitrary material constant, and $R = 8.3144621(75) \text{ J/K mol}$ the GAS constant. For an perfect viscous fluid, $n = 1$. Beyond plastic behavior the material will rupture. Materials can be “hardened” or “softened” to modify the plastic strain behavior. In GEOPHYSICS, the elastic–plastic behavior applies to the crust and mantle of the EARTH. Rheological stratification of the continental crust under stress can be defined with integral application of brittle friction and plastic flow. Deformation can occur in several ways: plastic, ductile, and brittle. Ductile materials will accumulate any permanently applied stress without macroscopically visible signs of fracture until the ELASTIC LIMIT is reached, at which point the material will disintegrate. Brittle deformation will experience MICROSCOPIC deformations, where grains of material will slide along each other and will break (crumble) past the yield point of the material. Viscoplasticity, in particular, is used to describe the flow of lave (*also see CREEP*) (see [Figure P.107](#)).

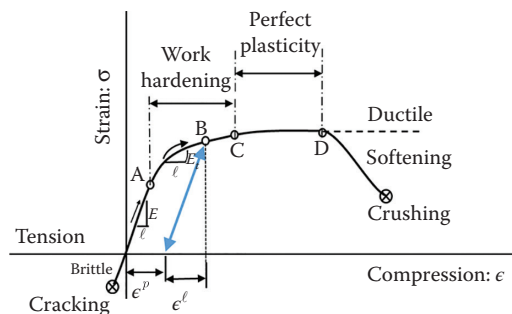


Figure P.107 Plastic strain.

P

Plasticity

[biomedical, chemical, mechanics] Process of irreversible deformations that are presumably based on an atomic scale, in biology on a cellular composition scale (in reference to stem cells). The deformations are formed when a threshold level or ELASTIC LIMIT is exceeded. The applied stress under plastic deformation is referred to a flow STRESS (see [Figure P.108](#)).



Figure P.108 Plasticity of an automobile, absorbing the external forces in deformation.

Plasticizers

[biomedical, chemical, mechanics] “Weak-makers,” phthalates. Chemical additives that will makes PLASTICS more pliable and maneuverable.

Plastics

[chemical, mechanics] Chemical grouping of organic polymers that are deformable, generally derived from both plant-based (e.g., CELLULOSE, from cotton; vegetable oils from seeds), naptha (natural gas) or oil-based ingredients. The ingredients are called resins. Plastics are for instance polypropylene and polyethylene. The building blocks are, for instance, propylene, ethane, and ethane (monomers), which are constructed into polymers. Polymerization can be accomplished either by means of addition or in condensation reactions; sometimes the POLYMER is formed at the interface of two LIQUID layers of different media. Plastics are frequently manufactured as composite materials. Not all plastics formed from plant-based ingredients are biodegradable, since the same monomers are formed in comparison to oil-based plastics. Plastics are usually formed into shape by injection molding or pressing/stamping (see [Figure P.109](#)).



Figure P.109 Plastics.

Plato (427–347 BC)

[general] Original name “Aristocle,” Greek scientist and philosopher, and founder of the modern concepts of optics and sight, contradicting the EXTRAMISION theory of VISION of his peers. However, his work was not recognized millennia later, after the publications by LEONARDO DA VINCI (1452–1519). Other work by Plato involves the description of MAGNETISM (*also see* LOADSTONE) in support of the work by Socrates

(469–399 BC). In MECHANICS, Plato had postulated the CONSERVATION OF ENERGY concept in his description of the exchange between heat and ACTIVITY (i.e., kinetic ENERGY) (see [Figure P.110](#)).



Figure P.110 Plato (427–347 BC), artistic impression statue at the Louvre in Paris, France.

Plücker, Julius (1801–1868)

[atomic, general, nuclear] Scientist from Germany (Prussian empire). Plucker realized that when the pressure in a CATHODE ray tube is low, the GLASS wall at the opposite side can be made to emit light. The location where LIGHT is emitted can be altered by applying a MAGNET to the side WALL of the tube.

He interpreted the light emission and MAGNETIC manipulation with the presence of ELECTRIC CHARGE and indirectly indicated the discovery of the electron in 1858 (see [Figure P.111](#)).



Figure P.111 Julius Plücker (1801–1868).

Plutonium ($^{244}_{94}\text{Pu}$)

[atomic, nuclear] Artificially produced radioactive ELEMENT. Plutonium-244 is very stable with a half-life of 82 000 000 years, decays into $^{240}_{92}\text{U}$ by ALPHA DECAY. Plutonium ($^{238}_{94}\text{Pu}$, plutonium isotope) was first made at the University of California in 1941 by high-speed collision of deuterons on uranium-238. Plutonium-238 is used as nuclear fuel on space ships. The Cassini probe and the Galileo probe are powered under thermo-nuclear reactors from plutonium-238. Another ISOTOPE, plutonium-239 has a FISSION reaction mechanism and used in nuclear weapons and certain NUCLEAR REACTOR power generators (see [Figure P.112](#)).

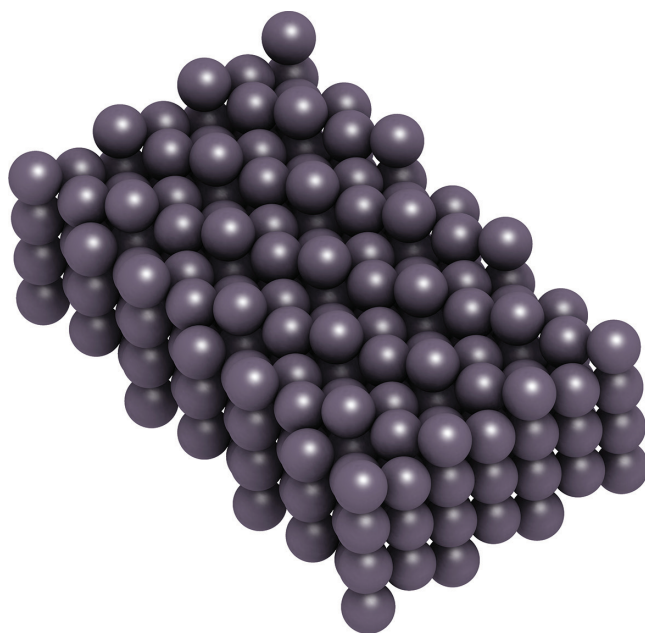


Figure P.112 Plutonium.

Plutonium Project

[general] See **MANHATTAN PROJECT**.

PMM1

[thermodynamics] **PERPETUAL MOTION** machine of the first kind. A hypothetical system with a cyclic process that does not endure an internal change in state (no **ENERGY** transfer); however, it produces work. There is a theoretical impossibility of such a device in existence or ever being developed since there is no energy produced but work would follow nonetheless.

PMM2

[thermodynamics] **PERPETUAL MOTION** machine of the second kind. A lossless mechanism based on a cyclic change in state that results in work. The number of constituents in the system will not change from state to state. This system is impossible to achieve. Assuming that there are different ways of achieving this process, one process is from one stable equilibrium, performing work, and reaching a new equilibrium with lower **ENERGY**. After subsequent work performed on the system, the new state will reach a **NONEQUILIBRIUM STATE**, which should be equivalent to the starting state but cannot be equivalent since the first state was an **EQUILIBRIUM STATE** and the third state is not.

Pneumotachometer

[biomedical, fluid dynamics] Device for measuring **GAS** flow in addition to the pressure difference over the device from input (pressure at the source) to output (external, ambient pressure). One particular application is in measuring the exhaled and inhaled breath and deriving the associated lung-volume (see [Figure P.113](#)).



Figure P.113 Pneumotachometer.

pn-junction

[electronics, general] Junction of a *p*-type material and an *n*-type material, forming a **DIODE**. The *p*-type material has a shortage of electrons (holes), while the *N-TYPE SEMICONDUCTOR* material has been treated to have a permanent surplus of electrons. The *pn*-junction forms a semiconductor diode. The **SCHOTTKY DIODE** is a metal–semiconductor *pn*-junction diode that uses the work function between the **METAL** and the semiconductor material to yield a **SCHOTTKY BARRIER**. The Schottky diode has **RECTIFIER** characteristics, with current profile: $I = I_r \left\{ \exp\left(\frac{qV}{nk_B T}\right) \right\} - 1$, where I_r represents the reverse leak current, q the charge, V the applied voltage, qV represents the bias potential, n is a factor that represents the idealistic character ($n = 1$ would be a perfect diode, $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann coefficient, and T the temperature at the junction. Step recovery diodes are *p-n* diodes with extremely fast recovery time due to the designed graded **FERMI-LEVEL** drop at the junction, thus minimizing the dwell time of the minority charge carriers. A **Zener**

diode is a p - n diode with a well-defined and sharp reverse bias breakdown voltage (up to several hundred volt). Another type of p - n diode is the tunnel diode. The tunnel diode has greater than average DOPING of both n - and p -TYPE SEMICONDUCTOR materials resulting in a Fermi level that is in the valence band for the p -type material and for the n -type material the Fermi level is in the CONDUCTION BAND (see Figure P.114).

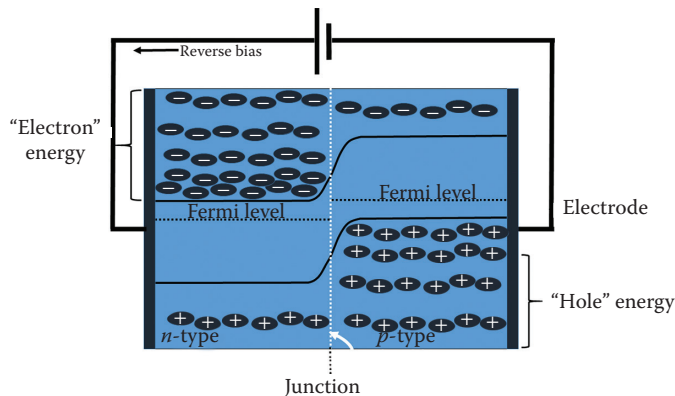


Figure P.114 *pn*-junction.

PNP transistor

[general] Semiconductor sandwich with *N*-TYPE SEMICONDUCTOR material has been treated to have a permanent surplus of electrons electronically positioned between two *p*-type materials with respective permanent shortage of electrons (holes). One *p*-type material is the “collector” while the other is the “emitter” and the *n*-type material provides the current quenching mechanism as the “base.” Transistors can be used to make rudimentary amplifier circuits with power supplies and resistors. The current gain for the TRANSISTOR is the collector current (ΔI_C) to base current (ΔI_B) ratio: $\text{gain} = \Delta I_C / \Delta I_B$, and similarly for the voltage gain (see [Figure P.115](#)).

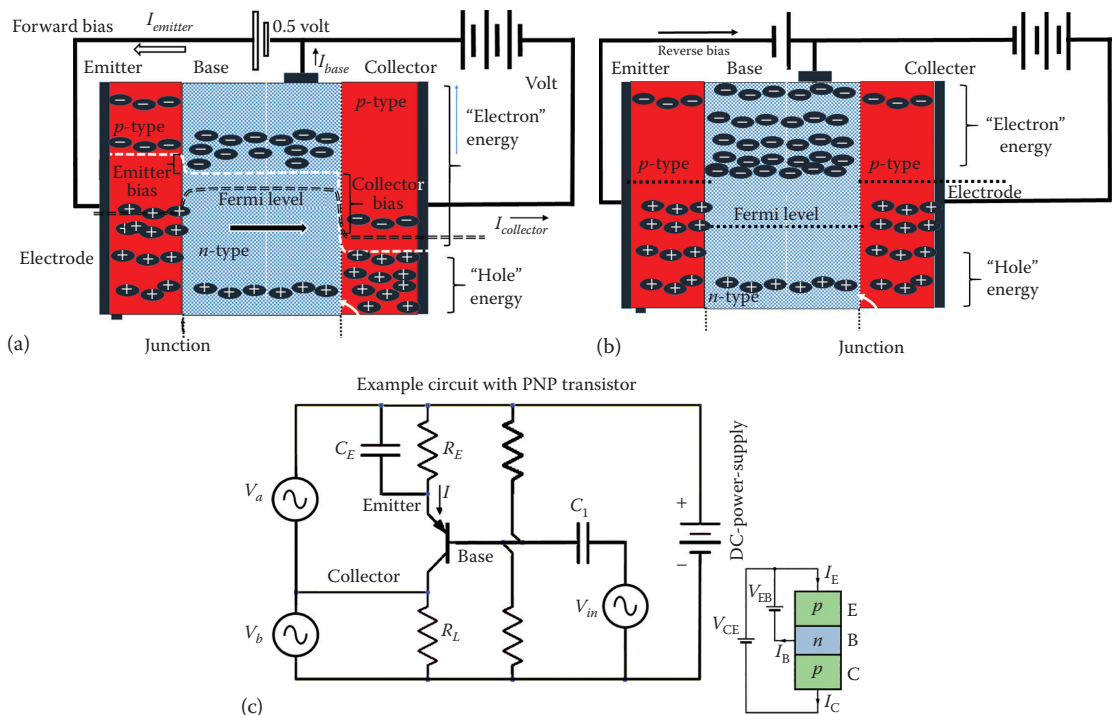


Figure P.115 (a–c) PNP transistor.

Po₂

[biomedical, chemical, fluid dynamics, general] Partial pressure of oxygen in a system, mixture of gasses. Gasses can be freely dispersed in liquids or chemically dissolved in fluids. In biomedical applications, this is used to determine the oxygen SATURATION of BLOOD with a PULSE OXIMETER (see RESPIRATION and PULSE OXIMETRY) (see [Figure P.116](#)).



Figure P.116 Graphical representation of the partial pressure of oxygen, in particular, relevant to respiration.

Pockels, Friedrich Carl Alwin (1865–1913)

[general, optics] Physicist from Italy. Pockels is best known for his research how in certain birefringent materials the refractive index can be altered under the influence of an externally applied electric field (see [Figure P.117](#)).



Figure P.117 Friedrich Carl Alwin Pockels (1865–1913). (Courtesy of Technische Universität Dresden, Germany.)

Pockels effect

[electromagnetism, energy, general, optics, thermodynamics] Change in the optical axis of a medium linear to the MAGNITUDE of an externally applied electric field, observed and described by FRIEDRICH CARL ALWIN

POCKELS (1865–1913) in 1893. Also considered to be part of the BIREFRINGENCE phenomenon. The local INDEX-OF-REFRACTION (n) can be described in a first-order Taylor series to depend on the local magnitude (location $\vec{r}$) of the ELECTRIC FIELD (E) as a function of time expressed as $n(E, \vec{r}, t) = n(\vec{r}, t) + [dn(\vec{r}, t)/dE]E(\vec{r}, t)$. The effect is used in the Pockels CELL for modulation of a beam of LIGHT, specifically in laser design, used in the MODE-LOCKED LASER (also see KERR EFFECT) (see Figure P.118).

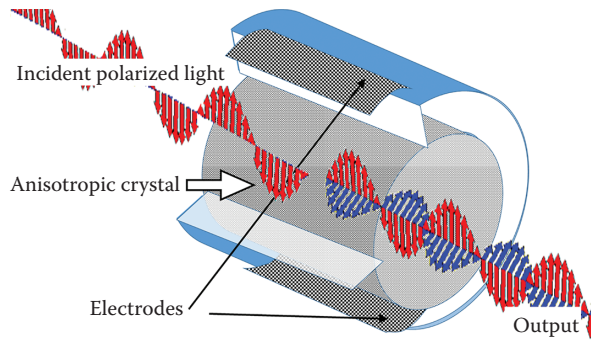


Figure P.118 The use of the Pockels effect in the Pockels cell, used to temporarily interrupt laser emission, creating a mode-locked laser beam.

Poincaré, Jules Henri (1854–1912)

[computational, general, thermodynamics] Theoretical physicist from France. Additionally, he was a mathematician and engineer. His computation work describes the shape of a rotating sphere turning into a “pear shape” in correlation with the momentum $L = I\omega$, where ω represents the ANGULAR VELOCITY and I the MOMENT OF INERTIA (which is a direct function of the shape of the revolving body). His most well-known work describes the MECHANICS of a rotating FLUID published in 1885: *Sur l'équilibre d'une masse fluide animée d'un mouvement de rotation*, in the *Acta Mathematica*. This work appears to be in follow-up of the work by CARL JACOBI (1804–1851) and COLIN MACLAURIN (1698–1746). The main reference of this work relates to the swing of a PENDULUM (see Figure P.119).



Figure P.119 Jules Henri Poincaré (1854–1912).

Poincaré section

[computational] Mechanism designed to discover structure in an attractor. The attractor for a dynamic system is the outlined CONTINUUM of physical parameter that the system tends to achieve irrespective of the starting conditions by physical evolution. The attractor can be plotted in a multidimensional graph. The Poincaré section follows from placing an arbitrary plane in the attractor graph and the orbit of the evolution of the attractor mechanism will intersect with the plane on several locations, which provides the marking outline for the Poincaré plane or section, providing an indication of structure of the attractor and hence the processes involved. Part of “chaos” theory.

Poinsot, Louis (1777–1859)

[mechanics] Physicist and mathematician from France. Poinsot is considered the father of geometrical MECHANICS. He was a contemporary, and colleague of French mathematician AUGUSTIN LOUIS CAUCHY (1789–1857) and the Italian mathematician JOSEPH-LOUIS LAGRANGE (1737–1813), all working at the École Polytechnique in Palaiseau near Paris, France (see [Figure P.120](#)).



POINSOT,

(Paris)

Membre de la Légion d'honneur.

1777-1859

Figure P.120 Louis Poinsot (1777–1859), engraved by Julien-Leopold Boilly.

Poinsot motion

[mechanics] Phenomenon in the Euler equation of MOTION calculations where two PRINCIPAL MOMENTS of inertia have the same value and direction, while only one force is present. Examples of Poinsot motion are found in gyroscopes and a spinning top. The Poinsot method was developed by LOUIS POINSOT (1777–1859) in 1809, which uses graphical interpretations of a body in MOTION based on conservation of KINETIC ENERGY and conservation of momentum. The KINETIC ENERGY (KE) of a rotating body with MOMENT OF INERTIA (I) and ANGULAR VELOCITY ω can be written, using the coordinate substitution $\bar{\rho}_m = \bar{\omega} / \sqrt{(2KE)}$, as $KE = (1/2)(I_1\omega_1^2 + I_2\omega_2^2 + I_3\omega_3^2)$, which yield: $I_1\rho_{m1}^2 + I_2\rho_{m2}^2 + I_3\rho_{m3}^2 = 1$, which is a description of an ellipsoid. The rotating ellipsoid in the graph represents the force-free motion, and the tangent plane is called the invariable plane (see [Figure P.121](#)).

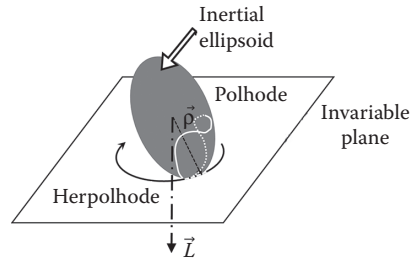


Figure P.121 Poinsot motion.

Point charges

[computational, general] Mathematical approximation for a geometry that is much larger than the source to allow for disregarding the boundary effects of the phenomenon in the SOLUTION of the situation. All charges are clumped together on an object of infinitesimal small size, or the charge itself is a single electron or PROTON charge. When the DISTANCE to the collection of charges is much greater than the diameter of the charge cloud the local effects of the charges are experienced as if they originate from the center of the charge collection. The point charge ($Q = \sum_i q_i$) will generate a Coulomb field at distance r resulting from Gauss' law expressed as $E_{\text{elec}} = (Q/4\pi\epsilon r^2)\vec{r}$, where $\epsilon = \epsilon_r\epsilon_0$, with $\epsilon_0 = 8.85419 \times 10^{-12} \text{C}^2/\text{Nm}^2$ the permittivity of free space and ϵ_r the RELATIVE PERMITTIVITY of the medium.

Point source

[acoustics, mechanics, optics] Any ENERGY representation that is considered to be located in an infinitesimally small volume at a single location in three-dimensional space. The size of the source often is taken with respect to the observed phenomena. The source will be isotropic and produce a SPHERICAL WAVE pattern. In certain approximations, the SUN can be considered a point source. In ACOUSTICS, a point source is for instance the emission from a piezoelectric device or SPEAKER, for this the ACOUSTIC INTENSITY will DECAY with $I \hat{=} 1/r^2$, whereas the pressure will decay as $P(r) \hat{=} 1/r$ with r the DISTANCE to the source. A point source can also be referenced as a mono-pole (mono-pole). The emitted wave front over TIME (t) will obey the WAVE EQUATION: $[\Delta - (n'/c^2)(\partial^2/\partial t^2)]V(\vec{r}, t) = 0$, where $\Delta = (\partial^2/\partial x_1^2) + (\partial^2/\partial x_2^2) + (\partial^2/\partial x_3^2) + \dots + (\partial^2/\partial x_m^2)$ is the Laplace operator for m -dimensional space, $V(\vec{r}, t)$ the phenomenon (in which case this represents harmonics the function becomes FREQUENCY ($\nu = \omega/2\pi$) dependent: $V(\vec{r}, t, \omega)$; acoustic electromagnetic etc., $n' > 1$ a constant, and c the speed of propagation of the phenomenon (e.g., speed of sound, speed of LIGHT). The spatial components of the wave equation will satisfy the Helmholtz equation. For an acoustic point source, the INTENSITY (I) over a period (T) is the average from the pressure and the PARTICLE motion ($v(\vec{r})$) expressed as $I = (1/T) \int_0^T P(\vec{r}, t) v(\vec{r}, t) dt$

Point vortex

[computational, fluid dynamics] In FLUID DYNAMICS the calculation of the CIRCULATION ($\Gamma = \oint v d\vec{l} = \int (\Delta \times \vec{v}) \cdot d\vec{s}$, where v is the velocity at the boundary of the tube generating the vortex, $\Delta = (\partial^2/\partial x_1^2) + (\partial^2/\partial x_2^2) + (\partial^2/\partial x_3^2) + \dots + (\partial^2/\partial x_m^2)$ the Laplace operator for m -dimensional space and $\vec{s}$ the surface with circumference c) associated with for instance a RANKINE vortex tube can be approximated for vanishing CROSS SECTION to provide the point vortex $\Gamma = \pi a^2 \omega_0 = \text{Constant}$, with ω_0 the angular velocity of rotation and $a \downarrow 0$ the vanishing radius (at which $\omega_0 \rightarrow \infty$) (see Figure P.122).

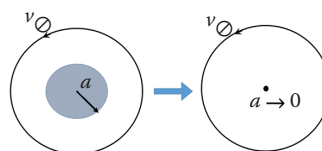


Figure P.122 Point vortex.

Poise (P)

[fluid dynamics, general, mechanics] Unit for DYNAMIC VISCOSITY, specifically in reference to liquids. One poise is equal to one-tenth pascal-second: $1P = 0.1 \text{ Pa s}$. The poise is named after the French physiologist POISEUILLE, JEAN LEONARD MARIE (1799–1869).

Poiseuille, Jean Leonard Marie (1799–1869)

[fluid dynamics] Scientist and physiologist from France. Jean Poiseuille introduced a range of flow concepts with wide ranging implications (see [Figure P.123](#)).



Figure P.123 Jean Leonard Marie Poiseuille (1799–1869).

P

Poiseuille flow

[fluid dynamics] Laminar flow in a horizontal tube with diameter D , with PRESSURE (P) drop in direction $\hat{x}$ that can be described by the POISEUILLE LAW, with flow velocity ($v(r)$) profile as a function of radius (r):

$v(r) = (1/16\eta)(dP/d\hat{x})(D^2 - 4r^2)$, where η is the viscosity of the LIQUID in flow.

Poiseuille number ($Ps = v_{ph}\eta/gd_p^2(\rho_s - \rho_f)$)

[fluid dynamics] Dimensionless number indicating the ratio of the net viscous force to the gravitational force, where v_{ph} is the PHASE VELOCITY of the WAVE phenomenon, η the KINEMATIC VISCOSITY, g GRAVITATIONAL ACCELERATION, d_p the (average) PARTICLE diameter, and ρ_s and ρ_f the respective density of the solid and the FLUID. The Poiseuille number applies primarily to LAMINAR FLOW conditions, and is mainly a function of the duct shape (e.g., circular, parallel plates).

Poiseuille's law

[biomedical, fluid dynamics] (also known as the Poiseuille equation) Expression for the flow rate through a horizontal tube as a function of the radius to the fourth power expressed by JEAN LEONARD MARIE POISEUILLE (1799–1869) in 1840. The average flow rate (Q_{flow}) is represented with respect to the radius of the tube (R) over a characteristic length (L) with a pressure gradient ($P_1 - P_2$) as

$Q_{\text{flow}} = (\pi R^4 / 8\eta) [(P_1 - P_2) / L]$, where η is the viscosity of the liquid in flow. The use of Poiseuille's law to define BLOOD flow has limited validity due to the nonlaminar behavior and the fact that the vascular walls are compliant, next to the influences of the direction of flow in an upright body, which may also be in MOTION. Also found under HAGEN-POISEUILLE LAW, with the independent contributions of the Prussian (now his birthplace is in Russia) scientist GOTTHILF HEINRICH LUDWIG HAGEN (1797–1884).

Poisson, Siméon Denis (1781–1840)

[astrophysics/astronomy, biomedical, computational] Physicist and mathematician from France, with additional training in MEDICINE. Poisson was a pupil of GIUSEPPE LUIGI COMTE DE LAGRANGE (1737–1813), ADRIEN-MARIE LEGENDRE (1752–1833) and PIERRE-SIMON DE LAPLACE (1749–1827). Poisson contributed to the interpretation and development of differential equations and partial differential equations. Siméon Poisson elaborated on the work by JOHANNES KEPLER (1571–1630) on the perturbations by planets and provided elaborate descriptions of charge migration as well as DIFFUSION characteristics and properties next to HEAT TRANSFER in association with SADI NICOLAS LÉONARD CARNOT (1796–1832). Siméon Poisson replaced ÉTIENNE LOUIS MALUS (1775–1812) on his death at the École Polytechnique in 1812. His mathematical work under Laplace also influenced the work of GEORGE GREEN (1793–1841) (see [Figure P.124](#)).



Figure P.124 Siméon Denis Poisson (1781–1840).

Poisson brackets

[computational] Recursive process of differentiation, extending out over partial differential equations; for instance applied to two functions f and g with variables p and q , this yields $\{f(p, q), g(p, q)\} = [(\partial f / \partial p)(\partial g / \partial q)] - [(\partial f / \partial q)(\partial g / \partial p)]$. In differential equations, the Poisson brackets provide a Hamiltonian operation (H) in MECHANICS as a binary operation. The connection with the Hamiltonian in mechanics is as follows: $\dot{p} = \{p, H(p, q)\}$, respectively, $\dot{q} = \{q, H(p, q)\}$. The Poisson brackets are an integral part of the HAMILTONIAN EQUATIONS OF MOTION. Specific rules associated with the Poisson brackets in differential expressions are $\{f, g\} = -\{g, f\}$; $\{f, f\} = 0$; $\{f, gb\} = g\{f, b\} + \{f, g\}b$; and $\{f, \{g, b\}\} + \{b, \{f, g\}\} + \{g, \{b, f\}\} = 0$, which are all natural properties of QUANTUM operators.

Poisson distribution

[computational] PROBABILITY theory describing the distribution of obtaining exactly n successes in N trials, as the limit of a binomial distribution $P_\chi = \lim_{n \rightarrow \infty} \{[N! / n!(N - n)!] p^n (1 - p)^{N - n}\}$, where P represents the probability and $\chi = Np$ the expected number of successes. The Poisson distribution is maximized under the condition $dP_\chi(n) / dn = 0$. The Poisson distribution was the brain child of SIMÉON DENIS POISSON (1781–1840).

Poisson equations

[biomedical, chemical] **DIFFUSION** of charges. $\nabla \cdot \vec{j} = d\rho_{\text{charge}}/dt = \nabla \cdot \gamma_{\text{cond}} \vec{E} = \gamma_{\text{cond}} (\nabla \cdot \vec{E}) = -\gamma_{\text{cond}} (\nabla^2 \Phi)$, where the first part expresses the continuity of charge, $\nabla^2 \Phi = \rho_{\text{charge}}/\epsilon = \nabla \cdot \vec{j}/\gamma_{\text{cond}}$, $\vec{E}$ the electric field, γ_{cond} the electrical conductivity of the medium, $\vec{j}$ the charge **FLUX** (per unit area), Φ the potential difference across the **BARRIER**, which is the **CELL MEMBRANE** in biology, ∇^2 the Laplace operator, ρ_{charge} the charge density, and $\epsilon = \epsilon_r \epsilon_0$, with $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space and ϵ_r the **RELATIVE PERMITTIVITY** of the medium, introduced by **SIMÉON DENIS POISSON** (1781–1840).

Poisson noise

[biomedical, electronics, electromagnetism] Random **SIGNAL** fluctuations in the registered detector value resulting from a limited **PHOTON** count. The source may be powerful enough, however, due to attenuation in a medium the photon count can be drastically reduced. The limited photon count may not reach threshold values for conversion into an electrical signal, but cumulative events may provide electron release. Photon emission during **X-RAY RADIATION** provides an example of the random generation of the X-ray photons in the emission process. Poisson noise stands in comparison to **GAUSSIAN NOISE**. Poisson noise is based on the initial efforts and conclusions by **SIMÉON DENIS POISSON** (1781–1840) on general phenomenological description.

Poisson's ratio (ν_p)

[fluid dynamics, geophysics, mechanics] Quotient of extensions normal to the **PRINCIPAL STRESS** vector over extensions parallel to the principal stress vector: $\nu_p = -\epsilon_x/\epsilon_y$, where ϵ_i is the strain in direction i . Note that Young's modulus is stress over strain. Poisson's ratio can, in geological applications, be derived from **SEISMIC WAVE-velocity** vector comparison. For a compressible medium $\nu_p < 0.5$, whereas for an incompressible medium $\nu_p = 0.5$.

Polar coordinates

[biomedical, computational, fluid dynamics, mechanics] Two-dimensional outline with two references; the **DISTANCE** with respect to a fixed origin, conveniently chosen, and the angular dependency with respect to a conveniently chosen reference line through the origin. This is superseded in three dimensions by cylindrical coordinates or alternatively spherical coordinates (see [Figure P.125](#)).

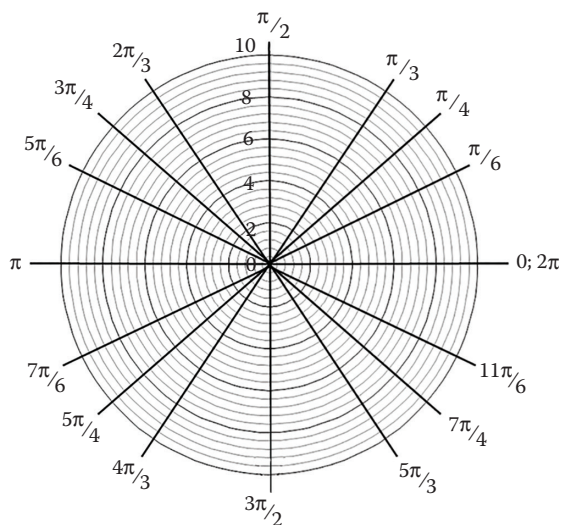


Figure P.125 Polar coordinates.

Polar moment of inertia

[biomedical, computational, mechanics] Geometrical outline of the distribution of the points within an arbitrary area ($\mathcal{A}$) for a two-dimensional “object” in relation to an axis of choice: $J_{\text{axis}} = \int_{\mathcal{A}} r_p^2 d\mathcal{A} \xrightarrow{\text{to } x\text{-axis}} \iint_{\mathcal{A}} y_p^2 dx dy$, where r_p represents the DISTANCE to the axis of choice. This is also known as the MOMENT OF INERTIA of a plane area, or the second moment area.

Polar nature of a medium

[biomedical, chemical, fluid dynamics, mechanics, thermodynamics] Materials (especially liquids) can on a molecular level be inertly polarized or can be induced to shift their ELECTRIC CHARGE concentration to create the equivalence of a DIPOLE. Water is a clear example of the natural polarity due to the arrangement of the two hydrogen atoms with respect to the single oxygen ATOM, where the hydrogen is arranged asymmetrically, with both atoms approximately at 120° with each other. Oils on the other hand are nonpolar. Both alcohols and the general classification of detergents are a special case that can mix with both water and OIL due to the induced polarity when in contact with water and the nonpolar behavior under a zero net charge exposure. Detergents are large molecules with a polar and a nonpolar end, which makes them ideal for MIXING with both water and oil (see Figure P.126).

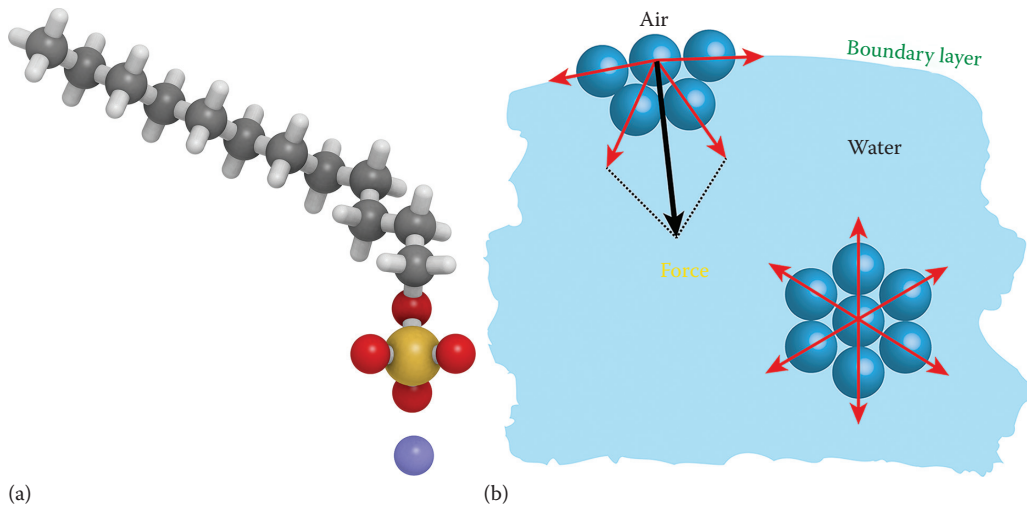


Figure P.126 Polarity of (a) detergent and (b) surface force of a polar medium.

Polarity of emf (electromotive force)

[electronics, general] The potential due to a surplus or deficiency of electron charges. For instance, a BATTERY has a positive and negative side, current flows per definition from positive to negative polarity.

Polarization

[general, nuclear, optics] Property of ELECTROMAGNETIC RADIATION, indicating the predominant angular direction of the electric field vector in a plane that is outlined by the direction of propagation coalescing with the normal to the plane, generally measured with respect to an arbitrary horizontal reference line. Certain animals can observe polarization, for instance the pygmy octopus, and it may communicate this way as well. The dung beetle and the field cricket for instance use the polarization of the LIGHT reflected by the MOON for navigation. Light reflecting from a surface will have a polarization direction that is outlined

by the orthogonal of the direction of propagation in the plane of the reflecting surface and the direction of propagation of the reflected WAVE (see [Figure P.127](#)).



Figure P.127 Dung beetle navigating the ball of dung for her breeding housing, at night under light as polarized when reflected by the Moon.

Polarization of light

[general] A transverse electromagnetic WAVE is plane polarized when the electric field oscillates in a single plane outlined by the direction of propagation, whereas a circularly polarized beam of LIGHT has the electric field perform a rotation around the axis of propagation in a circular pattern with DISTANCE traveled repeatedly per wavelength. Light generated by various sources, including the SUN and an incandescent lamp is unpolarized also referred to as NATURAL LIGHT (*also see MALUS' LAW*) (see [Figure P.128](#)).



Figure P.128 Sunlight by its nature is unpolarized. The reflection from the windshield of an automobile.

Polarization selective film

[chemical, general] Transparent sheet that facilitates the preferred transmission of LIGHT with a single angle of polarization. Iodine is linked to the POLYMER chain in a polyvinyl alcohol (PVA) sheet, which is stretched under raised temperature, forming aligned long chains of hydrocarbon molecules. The POLARIZATION angle lining up with the polymeric molecules will be transmitted. The concept was introduced in 1928 by EDWIN HERBERT LAND (1909–1991).

Polaroid™ film

[chemical, general] Light-sensitive POLYMER film constructed of NITROCELLULOSE (transparent) with embedded iodoquinine sulfate crystals invented by EDWIN HERBERT LAND (1909–1991) in 1928. Produced by the Polaroid Corporation® (with founder Edwin Land). Polaroid film produces a virtually instantaneous hard-copy photograph after a brief fixation process inside the CAMERA. The principle of the polaroid film was initially a polarizer, a sheet that allows only LIGHT with a single POLARIZATION direction to pass through. The initial synthetic polarizer sheet was clear polyvinyl alcohol that was heated and stretched. Subsequent DOPING with iodine formed a MICROSCOPIC wire structure that allowed only light with an electric field that lines up with the molecular chains of iodine to pass through. The first camera was the Polaroid Land Camera Model 95 loaded with the first Polaroid Land Film Type 40, which were first offered to the public in late 1948. The polaroid photographic film works as follows. Once the special light-sensitive film has been exposed the “PICTURE” rolls between two rollers that crack a pouch with chemicals that covers the exposed film and fixes the chemical processes so that they are no longer light sensitive. A short heating process fixes the chemicals to prevent any further chemical interactions. The ejected photograph was only in black and white for the first camera (using a single-layer silver compound), later converted to operate in COLOR by including three layers of RED, green, and blue emulsion that are all light activated, and the process takes approximately 45 s (see [Figure P.129](#)).



Figure P.129 Polaroid® camera.

Poles

[general, geophysics] Poles have various meanings, mainly indicating the fact that there are opposite properties involved with respect to location. Geographic poles of the EARTH indicate the connecting points on opposite sides of the world through which the axis of rotation passes, whereas the MAGNETIC poles are an indication of the beginning and end points on either side of the world where MAGNETIC FIELD lines connect; the two are not in identical locations. Moreover, the magnetic north and south poles DRIFT and have switched location several times in traceable history. The poles of a PERMANENT MAGNET are on opposite sides of the magnetic object, generally also referenced as NORTH and south poles. The MAGNETIC POLES were first described in 1267 by the French engineer PIERRE PELERIN DE MARICOURT (a.k.a. Peter Peregrine) (c. 1220–1270); however, MAGNETISM was known for centuries prior to that. Poles that are equal will repel, whereas opposite poles attract. The poles on a BATTERY are the respective positive and negative terminals (*also see* DIPOLE) (see [Figure P.130](#)).



Figure P.130 Compass indicating the orientation with respect to the Earth's magnetic poles.

P

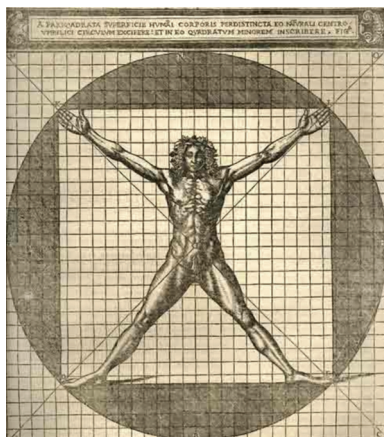
Pollio, Marcus Vitruvius (c. 80 BC–c. 15 AD)

[general] Roman scientist, engineer, and architect. According to Pollio (actually known as Vitruvius), nature is the inspiration to architecture. Birds and squirrels built nests; likewise humans erect housing from NATURAL MATERIALS. The Greek initiated architectural orders that linked biology to man-made structures: Doric, Ionic, and Corinthian. The order described in this culminated in understanding the HUMAN BODY,

perceived as the greatest **ENGINEERING** feat. This symbiosis led Vitruvius Pollio to define the Vitruvian Man, which was adopted and later drawn by **LEONARDO DA VINCI** (1452–1519) (see [Figure P.131](#)).



(a)



(b)

Figure P.131 (a) Artist representation of the likeness of Marcus Vitruvius Pollio (c. 80 BC–c. 15 AD) and (b) Vitruvian man. (Courtesy of *De Architectura* by Marcus Vitruvius Pollio [Como, 1521]. Shelfmark: 60.g.4. Copyright The British Library Board.)

Polonium ($^{84}_{209}\text{Po}$)

[atomic, nuclear] Radioactive, unstable “metallic” chemical **ELEMENT**, primarily found in uranium ores. Polonium was discovered by Marie (Many) **SKŁODOVSKA CURIE** (1867–1934) and her husband **PIERRE CURIE** (1859–1906) in 1898.

Polycrystalline solids

[general] Organized internal structure medium, often associated with metallic objects. A material that has no definite internal structure is amorphous, in contrast. Ordinary objects such as **METAL** spoons and metal cases are polycrystalline solids.

Polydimethylsiloxane (PDMS)

[biomedical, chemical] Chemical **ELASTOMER**, $\text{CH}_3[\text{Si}(\text{CH}_3)_2\text{O}]_n\text{Si}(\text{CH}_3)_3$. PDMS is a nontoxic semipermeable material (gas permeable) that is also transparent to **LIGHT** down to 300 nm. PDMS is often referred

to as an organosilicon, but is less expensive than silicon-based materials (“silicones”). Polydimethylsiloxane is an organic POLYMER that is used in many different applications, several in biomedical design; for instance contact lenses. Other consumer application is as a coating in shampoo, to make the hair slick and glossy.

Polymer

[biomedical, chemical] Synthetic compound, macro MOLECULE. The polymer matrix consists of repeated monomers (small molecular chains). In biomedical context, bone is considered a polymer, consisting of collagen and inorganic salts, comprised of carbonates and phosphates; alternatively, CELLULOSE is a polymer as well. Other biological polymers are proteins, starches, and latex. One of the most well-known and simple chemical polymers is polystyrene $(-\text{C}_6\text{H}_5)_n$ {MONOMER: C_6H_5 }, next to polyethylene $(-\text{CH}_2-\text{CH}_2)_n$. Other common consumer polymers are POLYDIMETHYLSILOXANE (PDMS), POLY(VINYLDENE) FLUORIDE (PVDF), and PVC (POLYVINYL CHLORIDE: $(-\text{CH}_2=\text{CHCl})_n$) (*also see* MONOMER) (see [Figure P.132](#)).

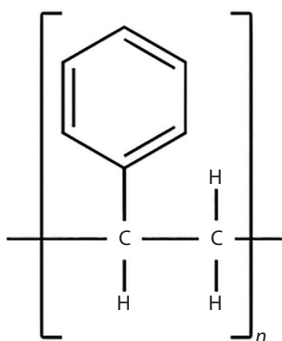


Figure P.132 Chemical structure of polystyrene polymer.

Polymethylmethacrylate (PMMA)

[biomedical, chemical, general] Transparent POLYMER, often used in place of GLASS, high strength making it shatterproof. Also known as acrylic glass; synthetic emulsion polymerization of methyl methacrylate, developed in 1928. Trade names include (but not limited to) Lucite®, Plexiglas®, and Perspex® (see [Figure P.133](#)).



Figure P.133 Plexiglas chairs.

Polypeptide

[biomedical, chemical] Amino-ACID monomers linked by peptide bonds to form a POLYMER structure. Often related to the formation of a polypeptide chain (see [Figure P.134](#)).

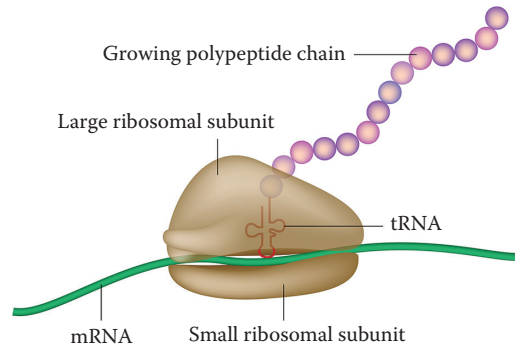


Figure P.134 Polypeptide in biological configuration.

Polytropic process

[astrophysics/astronomy, thermodynamics] Process that follows the CONTINUITY EQUATION for the linked properties for PRESSURE (P) and specific volume (V_s) as $PV_s^{n_p} = \text{Const}$, where n_p is the polytropic index; alternatively, with respect to ENTROPY (S) as a function of TEMPERATURE (T) it can be described as $T(dS/dT) = \text{Konstant}$. The polytropic index ($n_p = (c_p - \text{Konstant}) / (c_v - \text{Konstant})$), where c_p and c_v are the SPECIFIC HEAT under constant pressure or constant volume respectively, defines and characterizes the specifics of process. The concept of polytropic mechanism relies on the process path in the state diagram (i.e., P-V diagram; respectively T-S diagram), where several paths are possible and they intersect (polytropic path). Any closed system for GAS or VAPOR that involves HEAT TRANSFER and work can be described by a polytropic path. Polytropic process describes heat transfer, specifically associated with EXPANSION and contraction. In ASTROPHYSICS, this applies to fluids where the pressure is a function of the density, in solutions to the LANE-EMDEN EQUATION.

Polyvinyl chloride (PVC)

[biomedical, chemical, mechanics] Polymer chemical that has a wide range of applications, made by polymerization of vinyl chloride. PVC is a plastic that is a solid under normal conditions. PVC forms the basis for products such as pipes, vinyl siding, BLOOD bags, drink bottles, HEART bypass tubing, etc. It is the third most popular polymer after polyethylene and polypropylene. PVC poses significant health risks, primarily when exposed to incineration fumes and in dust form, specifically due to the high chlorine content. Chemicals known as dioxins are released during the manufacturing, or incineration of PVC.

Dioxins exposure can lead to problems in reproductive, respiratory (asthma), and developmental health as well as provide carcinogenic properties (see [Figure P.135](#)).



Figure P.135 Applications of polyvinyl chloride (PVC) in the formation of plumbing pipes.

Poly(vinylidene) fluoride (PVDF)

[acoustics, biomedical, chemical, mechanics] Thermoplastic polymer $-(C_2H_2F_2)_n-$. Versatile fluoropolymer used in biomedical applications to attract proteins (ADHESION) and in consumer applications for instance in the manufacturing of bottles and insulation on wiring. PVDF is a very strong material, as well as flexible, that can be electrically polarized and can withstand temperatures up to 149°C and down to -62°C and remain stable. Because of its electrical POLARIZATION (ferroelectric polymer, recognized in the 1970s), it has piezoelectric properties and is used in ULTRASOUND transducers and extremely small and thin pressure sensing devices. The PVDF TRANSDUCER can operate at frequencies above 15 MHz with low acoustic impedance and low residual electrical impedance. PVDF pressure transducers can be made in film format with minimal mass and size.

P

Pool, M. L.

[atomic, nuclear] (twentieth century) Scientist from the United States involved in the description of nuclear processes in 1935. One specific area of research by Pool was in monokinetic electron sources.

Population inversion

[general] Atomic or molecular artificial excitation with respect to GROUND STATE for the majority of excitable atoms/molecules. Population inversion is the essential and critical process in the mechanism of action for LIGHT amplification by STIMULATED EMISSION of radiation (LASER). The concept of population inversion was hypothesized by ALBERT EINSTEIN (1879–1955) in 1917. The Einstein theory of population inversion defines the phenomenological relations between external electric and/or MAGNETIC fields, interacting with a group of atoms. This interaction forms the elementary foundation when “laser” conditions can be accomplished. The primary condition to achieve the laser mechanism of action is the atomic/molecular population inversion. This situation is defined by the fact that a greater number of excited atoms are present in the laser medium than there are atoms in the ground state. In order to achieve this, the following conditions need to be analyzed. There will be a minimum amount of ENERGY required to raise the majority of atoms to the excited state. For this, the zeroth-order assumption is that all energy injected into the laser medium (the medium that has an ELECTRON DECAY process with an associated particular electromagnetic emission energy, i.e., single wavelength; in most cases, some lasers make use of a broad-band source, such as dye lasers)

provided to raise electrons to the excited state is 100% effective. In the case of 100% stimulation efficiency, only the electron energy lost due to light emission, resulting from stimulated emission in particular, will need to be replaced. The excited state is not necessarily a single energy band; most likely, the atomic structure will be composed of several bands that can be filled by supplying external energy excitation. Furthermore, those multiple excitation energy levels can be split further in modes. These excited energy modes will have their own associated characteristic lifetimes. The energy modes describing one single energy band can be referenced by the notation N_m , each individual mode with respective average lifetime τ_e . A relationship defining the MINIMUM ENERGY requirements for exciting (pumping) the laser medium to EXCITED STATES can be developed based on a range of assumptions. In zeroth-order approximation, the idealized situation of a system with simply two energy levels can be considered, consisting of the GROUND state energy and the excited state. The energy supplied as input for the excitation of a two-level system raises the ground state condition to an excited state in an acceptable first-order description for the process. The supplied energy is assumed to be provided by an external ELECTROMAGNETIC FIELD; however, also an ELECTRIC field alone or MAGNETIC FIELD or chemical reaction can satisfy the energy requirements. The electromagnetic input satisfies the Planck relationship $W = h\nu = h(c/\lambda)$. The additional assumption is that the supplied photon energy W matches exactly the difference in energy between the excited energy level E_2 and the ground level: E_1 : $E_2 - E_1 = h\nu_0 = h(c/\lambda_0)$. Because of the fact that this is a two-energy level system, the emissions will also only be composed of one single wavelength λ_0 or frequency $\nu_0 = \lambda_0/c$, with $c = 2.99792458 \times 10^8$ m/s the speed of light. The resulting boundary conditions for the “pumping” POWER (P) of the excitation source is hence: $P = N_m h c / \lambda_0 \tau_e$, where N_m is the necessary number of atoms to be promoted to an excited state. The rate of stimulated emission that fuels the process of laser emission is directly proportional to the absolute value of the difference between the number of atoms raised to the excited state N_2 , to the number of atoms sustaining the ground state N_1 , defined as $N_2 - N_1$. This difference between the excited state and the ground state (two [2] level system) is linearly proportional to the ratio of the average lifetime with respect to the PHOTON emission associated with the decay process τ_e , in reference to the average lifetime that belongs to the excited state τ_e , defined as $\Delta N = N_2 - N_1 = N_m \tau_e / \tau_e$. Although spontaneous emission is not a consideration, it will initially be the driving “force” for the decay process and is defined as $dN_2/dt = -A_{21}N_2$, where A_{21} is the PROBABILITY coefficient defining the spontaneous emission process, also known as the Einstein A_{21} coefficient, and has the dimension of time⁻¹. The light energy absorption process for stimulation will adhere to the same principles, outlined as $dN_1/dt = -R_{12}N_1 = -B_{12}U(\nu_0)N_1$, where B_{12} is defined as the absorption coefficient, and also has the dimension of time⁻¹. Similarly, the stimulated emission process can be described as $dN_2/dt = -R_{21}N_2 = -B_{21}U(\nu_0)N_2$, where B_{21} is defined as the stimulation probability, where B_{21} also has the dimension of time⁻¹ to remain consistent in the phenomenological description. The stimulation probability coefficient B_{21} depends on the energy-level transition only, and is hence a function of the particular ATOM used in the “laser medium,” thus providing the unique emission wavelength for each medium. The decay of the respective energy occupation populations N_1 and N_2 also depends on the radiance of the incident light, that is, the MAGNITUDE of the incident excitation photon FLUX, and additionally depends on the cross-sectional area representing the stimulation excited atom—target: $R_{21} = \sigma_{21}\Phi$, where R_{21} is the rate of stimulated emission, Φ is the incident electromagnetic flux, and σ_{21} represents the “target area” stimulated emission CROSS SECTION. In this process, the coefficients A_{12} , B_{21} , and B_{12} are referred to as the Einstein coefficients. In the population inversion process, there is a requirement for achieving a Metastable state. The metastable state is a function of the interaction of various ELEMENTS in the laser medium in the presence of other elements (i.e., the base medium matrix, doped with the excitable atoms used for the stimulated emission process), and one is required to account for the interaction of this atomic matrix with the energy structure of the neighboring atoms. This will be part of the second-order approach. Still back to the two-level system, the decay processes as a function of time (i.e., decay rate) for the energy levels N_1 and N_2 are defined by the following rate equations: $dN_2/dt = -A_{21}N_2 + B_{12}U(\nu_0)N_1 - B_{21}U(\nu_0)N_2$; $dN_1/dt = -dN_2/dt$. Once again employing the Planck’s black-body radiation equation (known as PLANCK’S LAW) for a BLACK BODY presumably at “virtual” temperature T , the emission of ELECTROMAGNETIC RADIATION with spectral profile $U(\nu)$ can be defined as $U(\nu_0)d\nu = (\nu^2/c^3)h\nu \{1/(\exp[h\nu/kT] - 1)\} d\nu = e'h\nu < n > d\nu$, where e' represents the EIGENVALUE for the RESONANCE energy density associated with the emitted photons, per photon, and n represents the average number of photons present in each respective resonance energy density.

The occupation of the respective energy levels N_1 and N_2 while operating under thermal equilibrium, satisfies the condition: $N_2/N_1 = (g_1/g_2) \exp[-h\nu/kT]$, where g_1 and g_2 are representing the respective RADIATION weight for the various energy levels. By definition, under thermal equilibrium the decay rate from level 1 is equal to the decay rate from level 2, and hence neither level will experience no decay what so ever:

$dN_1/dt = dN_2/dt = 0$. As a result of this particular boundary condition the following can be derived:

$-A_{21}N_2 + B_{12}U(\nu_0)N_1 = B_{21}U(\nu_0)N_2$. This can be rewritten as $[A_{21}N_2 + B_{21}U(\nu_0)]N_2 = B_{12}U(\nu_0)N_1$,

providing the electromagnetic field condition during population inversion:

$U(\nu_0) = A_{21}/[B_{12}(N_1/N_2) - B_{21}]$. Based on the conditions of thermal equilibrium between the two energy levels, and including the Planck black-body radiation, the Einstein coefficients can be shown to be correlated to each other as $B_{12}(g_1/g_2) = B_{21}$, and $(\nu^2/c^3)B_{21} = -A_{21} = U_e(\nu_0)B_{21}$. The condition $U_e(\nu_0) = (n^3/c^3)$ defines the spectral energy density for the situation of one (1) photon in each respective eigenvalue OSCILLATION, under the condition that the average number of photons present in each eigenvalue oscillation equates to only one single photon. This condition represent the fact that under an external field during stimulated emission this process equates to spontaneous emission, where only one single photon is allowed in each energy configuration. This condition is by definition satisfied based on the PAULI EXCLUSION PRINCIPLE as well as Schrödinger conditions and the de Broglie orbital constraints. The fact that in a real atomic energy configuration, the electron energy levels are split up due to the orbital constraints imposed by the BOHR ATOM model, the laser emission will not necessarily consist of a single wavelength, but rather be composed of spectral emission with a linewidth. This linewidth will be confined and defined by the choice in elements used to construct the LASER excitation medium. To summarize: the stimulated emission will dominate under population inversion $n > 1$, while for $n < 1$ the prevailing mechanism of light emission will be based on spontaneous emission. In order to harness the photons in the LASER medium, the laser medium has an optical construction known as a cavity that is confined by mirrors on either side, one side with slightly less than perfect reflectivity allowing laser light emission. The mirrors on opposite sides of the laser medium create an oscillator, or under specific boundary conditions a resonator (*also see LASER*).

Porphyrins

[biomedical, chemical] Sensitizer organic chemicals, which are neutral and nontoxic in their GROUND STATE but become chemically active when excited by a reagent medium, either chemical or energetic (e.g., photon energy). The porphyrin structure forms a macrocyclic structure, consisting of four pyrrole rings with joining molecular segments, primarily =CH-. Porphyrins consist of conjugate acids that are forming ligands that bind to metals (e.g., IRON in "heme"). The two most well-known porphyrins are chlorophyll (oxygen process in plant leaves) and heme as cofactor to the hemoglobin protein in BLOOD, used to acquire and loosely bind oxygen and carbon dioxide in the RESPIRATION system. One particular biomedical application is in PHOTODYNAMIC THERAPY to treat cancer through light-mediated chemical process that results in CELL death. Other chemical integrations are by means of for instance

pheoporphyrin, also known as a petroporphyrin. Pheoporphyrin is a geologic porphyrin found in coal, crude oil, sedimentary rocks, or oil shale (see [Figure P.136](#)).

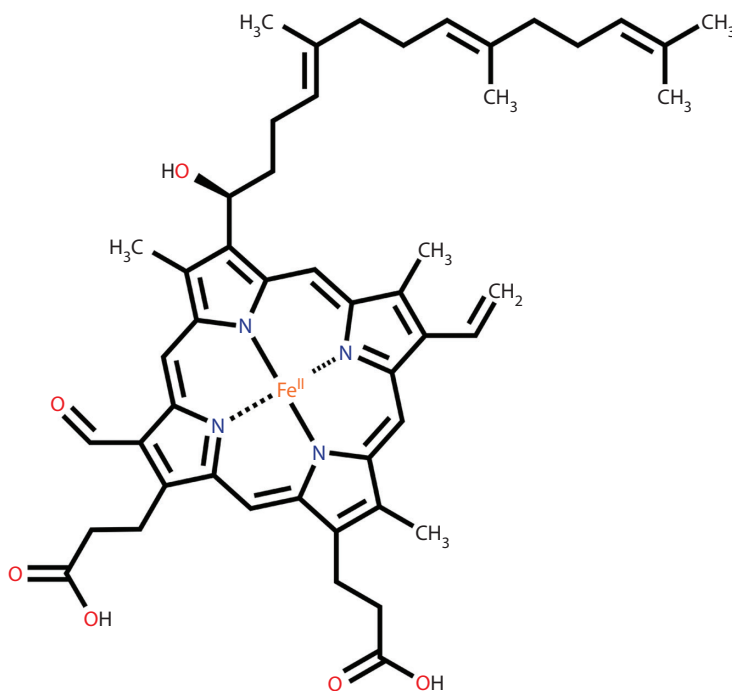


Figure P.136 Heme porphyrin, cofactor, and integral part of the hemoglobin protein, used for the transport of oxygen by red blood cells.

Positive charge

[general] Net charge with value that has opposite sign of the charge of an electron; alternatively, with a charge that repels protons. Charge is quantized, on an atomic level by PROTON value and as a material based on the amount of missing electrons with respect to a neutral electric state. An object made from GLASS that is rubbed with silk or flannel will become positively charged, transferring electrons from the glass to the cloth. The existence of charges can be dated back to the rubbing of AMBER with fur, as described by PLATO (427–347 BC). The nomenclature of positive and NEGATIVE CHARGE (introducing the hypothesis that there are only two types of charges) was introduced by the scientist and statesman (founding father) from the United States BENJAMIN FRANKLIN (1706–1790), and was based on the presumed transfer of positive charge, later found to be a misinterpretation. Franklin's proposition was based on the observations by the scientist and astronomer from Great Britain STEPHEN GRAY (1666–1736) in 1730.

Positive displacement pump

[fluid dynamics] Machine that has as the mechanism of action for flow the reduction of volume of a chamber holding the liquid (see [Figure P.137](#)).

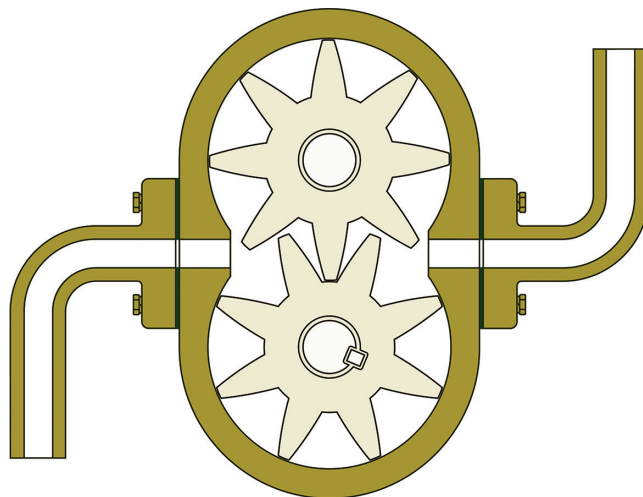


Figure P.137 Example of positive displacement pump: gear pump.

Positive ions

[atomic, nuclear] Atom or MOLECULE that is missing one or more electrons (see [Figure P.138](#)).

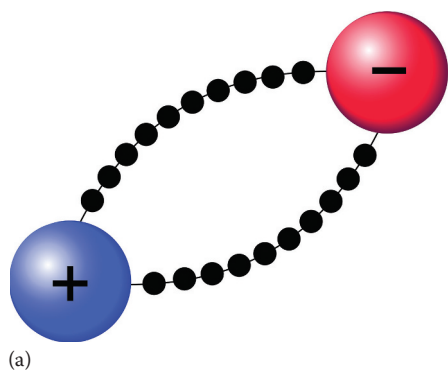


Figure P.138 (a) Positive ion interacting with negative ion, attraction and (b) lithium ion battery, popular rechargeable battery in most electronic portable devices.

Positive lens

[general] Lens that has a positive focal length and generally produces a magnified IMAGE with magnification greater than one (1) and produces a real image, providing the boundary conditions that are supporting the application. A positive lens is a converging LENS. Keep in mind that a converging lens with the object

placed at a DISTANCE closer than the FOCAL POINT will create a virtual image. The most well-known example of a positive lens is a loop (see Figure P.139).



Figure P.139 Example of positive lens, or loupe.

Positive rays

[atomic, nuclear] During the CATHODE ray experiments in 1886 by JOSEPH JOHN THOMSON (1856–1940), the observation was made that on the opposite side of the side of the tube where the ANODE is positioned and the CATHODE RAYS are fitting the GLASS window, other emissions were recorded that could be deflected by MAGNETIC fields, however, responding in opposite manner to the cathode rays. Thompson named them positive rays. The cathode ray tube from the late 1900s was preceded by the CROOKES TUBE, invented by the physicist and chemist from Great Britain SIR WILLIAM CROOKES (1832–1919) in 1870, resembling the modern neon-gas-discharge tube. This phenomenon was predated by observed and documented low-pressure discharges in a BAROMETER by the French astronomer JEAN PICARD (1620–1682) in 1675; however no conclusive evidence of the mechanism of action in both cases, or the values of the charges were involved.

Positron (β^+)

[astrophysics/astronomy, atomic, general, nuclear, quantum, thermodynamics] Positive counterpart of the electron, also sometimes referred to as the antielectron. The positron was predicted by the DIRAC EQUATION. The positron was discovered in 1932, and has an equivalent ENERGY of $E = mc^2 = 0.511$ MeV. The positron resulted from investigations into the COSMIC RAYS.

Positron annihilation

[atomic, biomedical, solid-state] Particle emitted by a radionucleotide ISOTOPE after a relatively short half-life. The positron will be emitted from a nucleotide during DECAY and subsequently annihilated after a relatively short lifetime (examples of RADIONUCLIDE half-life and inherent ENERGY are ^{18}F : 110 min, $E = 0.64$ MeV; ^{11}C : 22.4 min, $E = 0.96$ MeV; ^{15}O : 2.1 min, $E = 1.72$ MeV, where fluoride [^{18}F] is in a RADIOPHARMACEUTICAL: fludeoxyglucose [FDG]) with any of the many free electrons in the medium, specifically applied to biological media for imaging purposes in POSITRON EMISSION TOMOGRAPHY (PET). The annihilation process generally releases energy in excess of $E > 1.2$ MeV. The annihilation energy is released as two identical gamma (Γ) quanta with $E_\gamma = 511$ keV. These QUANTA are emitted in perfectly opposite directions. The energy balance for the positron annihilation process and the gamma pair production is described as $E_{\text{positron}} + E^{\text{kinetic}} + E_{\text{electron}} \geq 2E_\gamma$. The rest energy is derived from the difference in energy of the isotope and the annihilation product. In addition to the rest energy of the electron (E_{electron}) and the positron (E_{positron}) respectively, there can be positron or electron MOTION with respective kinetic energy E^{kinetic} . The nuclear

energy of the decay reaction follows from the quantum PHYSICS using the mass-energy equivalence, providing the REST MASS energy as $E = mc^2$, where m is the mass of the object and $c = 2.99792458 \times 10^8$ m/s the speed of LIGHT. The photon energy follows $E = h\nu$, where $h = 6.626068 \times 10^{-34}$ m² kg/s is PLANCK's CONSTANT and ν the frequency of the PHOTON. This yields $m_p c^2 + m_e c^2 = 2h\nu_\gamma$, where m_p is the mass of the positron and m_e the electron mass. Filling in the mass equivalent energy for each respective component yields $511 \text{ keV} + E_{\text{positron}}^{\text{kin}} + 511 \text{ keV} \geq 1.022 \text{ MeV}$. Only concurrent emission of two 511 keV gamma quanta is considered an indication of positron release (*also see ANNIHILATION*) (see [Figure P.140](#)).

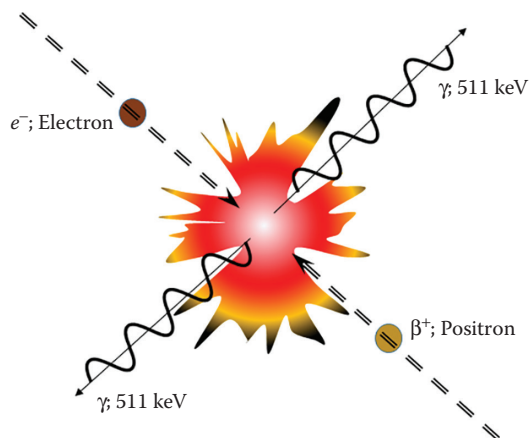


Figure P.140 Positron annihilation and gamma pair emission.

Positron decay

[nuclear] See BETA DECAY.

Positron emission tomography (PET)

[atomic, biomedical, energy, general, imaging, nuclear, solid-state] Nuclear imaging technique that produces images by means of introduction of radioactive isotopes that will emit a positron at a relatively short half-life. This imaging technique offers the capabilities to determine METABOLIC ACTIVITY of living organisms through incorporation of a Trojan horse ISOTOPE in the cellular METABOLISM obtained through radioactive labeling. The short-lived positron-emitting radionuclide can be detected noninvasively for imaging purposes by specialized equipment. Specific crystals, for instance bismuth germanate (BGO), convert the high-energy gamma photons into lower ENERGY photons. The visible light photons can subsequently be collected by a semiconductor array, such as a CCD (charge-coupled device) ELEMENT. The CCD array converts the PHOTON energy into electrical data, registered and located in three-dimensional space by the tomograph ELECTRONICS. The RADIOPHARMACEUTICAL that is administered contains radioactively labeled chemical substances using constituents that are identical, or chemically equivalent, to naturally occurring ELEMENTS in the body. Radioactive labeling pertains to the fact that one ATOM in a MOLECULE is replaced by a radioactive equivalent, a radionuclide. Examples of radioisotopes used in PET imaging are, for instance, ^{11}C , ^{18}F , ^{13}N , and ^{15}O . All the short-lived radioisotopes used in PET scans DECAY by positron emission. Positrons (β^+) are positively charged electrons. Positrons hence have the same mass and rest energy as an electron. Positron emission isotopes are introduced in the BLOOD stream to finally be incorporated in the organ or tumor of interest. Imaging is made possible by the positron–electron annihilation process, which emits two gamma rays in opposite direction. A specially designed detection mechanism in a tomograph detecting the MAGNITUDE and detection sequence of the gamma photons and subsequently derives the isotope's location and concentration by interpolation, transforming the received SIGNAL in a three-dimensional IMAGE. The PET visualization provides the tools to identify normal and abnormal activity in living tissue. This is in contrast to X-RAY computed tomography (CT), which principally renders anatomical images. PET measures chemical

changes in the tissue that can be used to identify metabolic activity that is not consistent with normal healthy tissue. Analogously, MAGNETIC RESONANCE IMAGING (MRI) can also measure specific metabolic activity with the specific limitation to blood oxygenation consumption. In the annihilation process of the constituent as an example, fluoride is stabilized by removing a POSITIVE CHARGE from the NUCLEUS through the conversion shown in the chemical reaction: $^{18}_9\text{F} \rightarrow ^0_{+1}\text{e} + ^{18}_8\text{O}$. A special version of PET is SINGLE-PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT) (see [Figure P.141](#)).

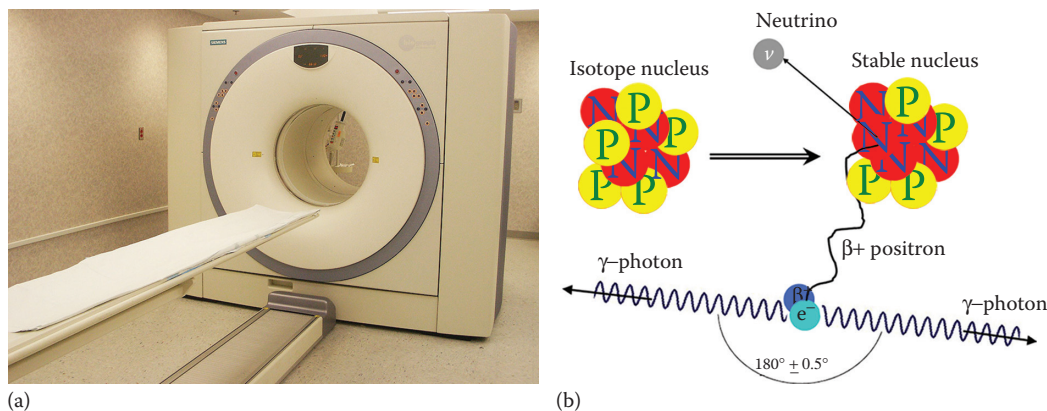


Figure P.141 (a) Positron emission tomography equipment (PET) and (b) PET mechanism of action.

Positronium

[atomic, nuclear] Metastable, ISOLATED SYSTEM consisting of an electron and the antiparticle: positron, bound as a single hypothetical atomic structure, predicted in 1932, detected in the 1950s. The positronium energetically resembles a HYDROGEN ATOM; however, positronium does not have the positron as the NUCLEUS but as a partner in orbit. The positronium decays with the emission of two gamma QUANTA, each at 511 keV. Positronium is referred to as an “exotic” atom, which defines an altered atom in which one or more nuclides have been substituted by other type particles of the same charge in different ENERGY setting, not necessarily with same total energy (see [Figure P.142](#)).

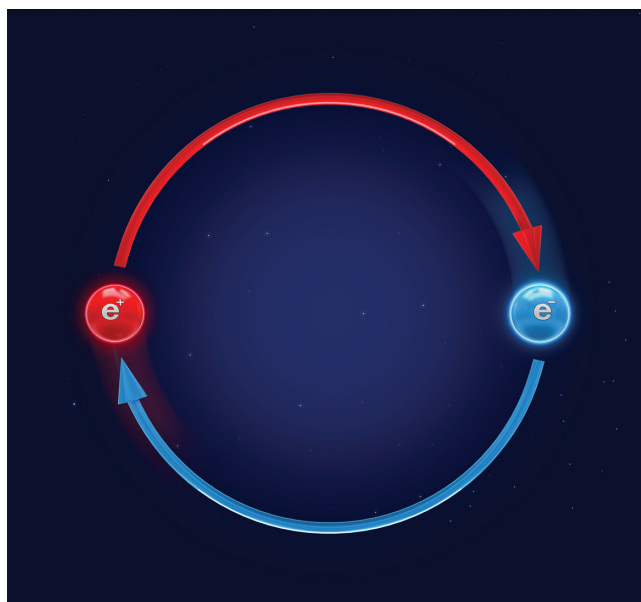


Figure P.142 Positronium.

Potassium ($^{39}_{19}\text{K}$)

[biomedical, chemical] Mineral, ALKALI METAL. In biology, potassium is one of the essential constituents of cells and tissues. Potassium performs a critical function in most muscular functions and is in integral part of the MEMBRANE POTENTIAL.

Potassium chloride (KCl)

[biomedical, chemical] SALT. In many facets similar to SODIUM CHLORIDE (conventional table salt: NaCl).

Potential (V)

[general] Referring the electrical potential that is associated with a charge accumulation and the work requirements for transporting a charge to or from the charge cluster. The potential is the POTENTIAL ENERGY (PE) of a charge in the vicinity of a charge grouping per unit charge: $V = (\text{electrical} - \text{PE})/\text{charge}$. The potential energy results from the electric field emanating from the charge cluster. The potential difference between two locations is equal to the work performed moving a charge between the two locations, per value of the moving charge. The work (W) performed is the force on the charge multiplied by the DISTANCE traversed (d): $W = Fd$, where the FORCE (F) is the charge to be moved multiplied by the ELECTRIC FIELD (E), $F = dE$. The electric field is the potential over the distance $E = V/d$ (also see COULOMB LAW and VOLTAGE).

Potential barrier

[atomic, energy, quantum] A potential ENERGY discontinuity, or slope (BARRIER) expressed as electrical potential, that influences the SOLUTION to the SCHRÖDINGER EQUATION for the transportation of a charged particle (NUCLIDE, electron) through a charge cloud. The energy barrier can be the difference between GROUND STATE and excited state of an atomic electron. The PROBABILITY of crossing the barrier will be a function of the kinetic energy of the PARTICLE with respect to the barrier "height" (MAGNITUDE). The probability (P_{chance}) of passing a mass (m_0) with charge through the barrier (over a DISTANCE $x_2 - x_1$) can be written as proportional to the potential magnitude as $P_{\text{chance}} \approx e^{-\gamma_{\text{barrier}}}$, where $\gamma_{\text{barrier}} = (2/\hbar) \int_{x_1}^{x_2} \{2m_0 [V(x) - \text{KE}]\}^{1/2} dx$, with $\hbar = h/2\pi$ ($h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ PLANCK'S CONSTANT) (also see BARRIER PENETRATION and TUNNELING) (see Figure P.143).

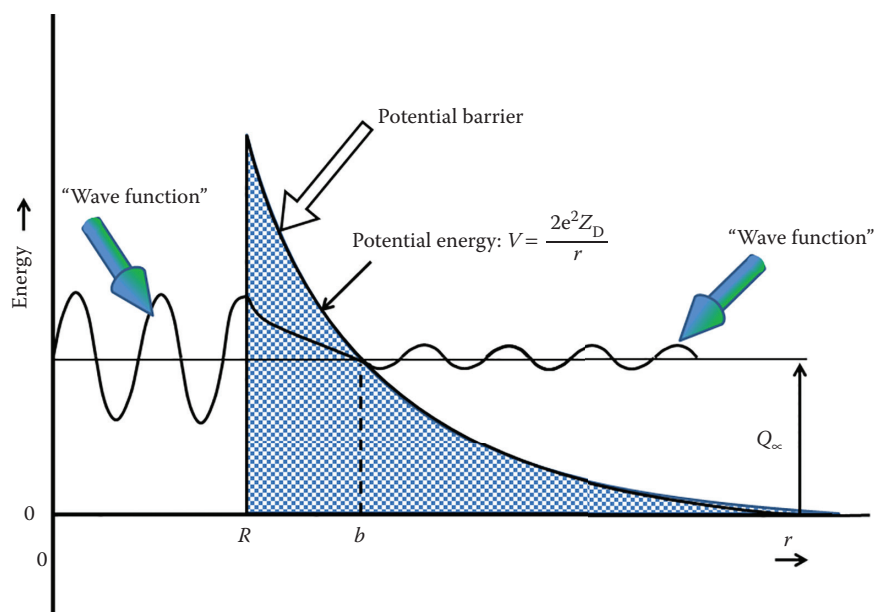


Figure P.143 Potential barrier as part of a nuclear or atomic energy model. The probability of escape from the nucleus, respectively atom is proportional to the "height" of the barrier.

Potential difference

[biomedical, energy, general] The difference in potential between any two points in a circuit; the work required to carry a unit POSITIVE CHARGE from one point to another (*see* POTENTIAL or ELECTRICAL POTENTIAL as well as VOLTAGE) (*see* Figure P.144).

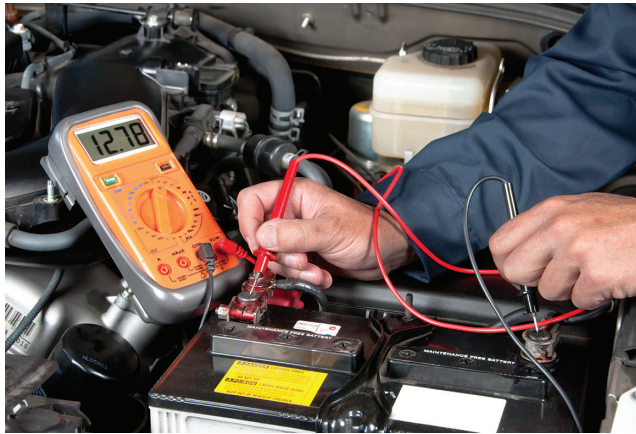


Figure P.144 Potential difference for a battery.

Potential energy (PE)

[general, mechanics, nuclear] The ENERGY that a body possesses by virtue of its location, external exposure, or mechanical attachments that it can potentially release in another form of energy (*Note: CONSERVATION OF ENERGY*). The potential to release energy can be made in reference to any point in space, where the work performed (W) to bring an object from one point to another point in space is the difference in potential energy between those two points: $W_{21} = PE_2 - PE_1$. Potential energy is expressed for location as $PE(x, y, z) = \rho V g s(x, y, z)$, where ρ is the density, V is the volume of the object, $\rho V = m$ is the mass of the object at rest, and $s(x, y, z)$ is the location of the object with respect to a point of reference, primarily height. One form of external exposure is a DIPOLE in an external MAGNETIC FIELD ($\vec{B}$), which has the potential of generating a TORQUE. The potential energy of the dipole (e.g., current loop) with MAGNETIC DIPOLE moment ($\vec{M}_{\text{current}} = NIA\vec{n}$) is expressed as $PE = -\vec{M}_{\text{current}} \cdot \vec{B}$, where I is the current in the loop, N the number of loops in the device carrying the current, A the area outlined by the loop, and $\vec{n}$ a unit vector in direction perpendicular to the plane of the loop, whose direction can be found by applying the right-hand rule. Additionally, for a spring, the mechanical attachment of an elastic device has the potential to release energy when the object is removed from the state of equilibrium, expressed as $PE = (1/2)ks^2$, where k is the spring constant and s is the displacement from equilibrium. Another form of potential energy is the potential of becoming engaged in a chemical reaction or nuclear degeneration (e.g., breaking down of isotopes). The potential energy stored in a SOLENOID with a magnetic field B may depend on the location within the solenoid and is frequently defined as energy density per unit VOLUME (V) as $PE/V = B^2/2\mu_0$, where μ_0 is the DIELECTRIC permeability of VACUUM. Similarly, the potential energy of a CAPACITOR with electric field E

between the plates is defined per unit volume as $PE/V = (1/2) \epsilon_0 E^2$, where ϵ_0 is the dielectric permittivity of vacuum (see Figure P.145).



Figure P.145 Example of potential energy resulting from elevation converted into hydroelectric energy.

Potential energy of a liquid surface

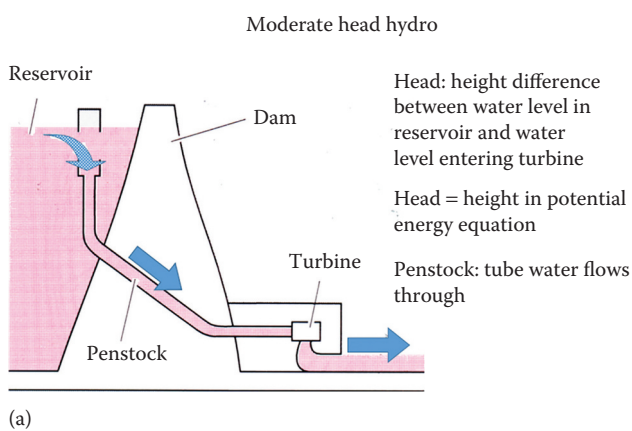
[biomedical, chemical, fluid dynamics, mechanics, thermodynamics] Molecules in the main body of a LIQUID are subject to thermal agitation and the internal forces on the molecules from neighboring molecules, and gravity will fluctuate but on average have zero balance, while the surface molecules are subject to an attractive force that maintains the molecules in the liquid. The molecules at the surface hence are considered to possess a potential ENERGY greater than the internal molecules of the liquid. The SURFACE TENSION provides the foundation for the SURFACE POTENTIAL ENERGY. The surface will continuously seek a condition of minimal potential energy, meaning that the surface will tend to shrink if allowed to assume minimum surface area with lower potential energy since the work needed to stretch the surface is counteracted by the potential energy. This also explains that a droplet in AIR will tend to take on a spherical shape, having the smallest area for any mass and volume. The surface potential is directly linked to the surface tension, however, with a correction for the MENISCUS curvature at the edge of the surface. The ANGLE of the surface with the WALL is represented by θ measured with respect to the wall above the liquid surface, giving the ratio of surface tension (σ_{surface}) to surface potential energy (γ_{surface}) as $\cos \theta = -\gamma_{\text{surface}}/\sigma_{\text{surface}}$ (see SURFACE TENSION).

Potential flow

[fluid dynamics] In FLUID DYNAMICS a “potential function” $\phi(x_1, x_2, t)$ can be defined that outlines the conformation to the CONSERVATION LAWS, with $\nabla \times \nabla \phi = 0$, while for IRROTATIONAL FLOW the average VELOCITY ($\vec{v}$) is defined by $\vec{v} = \nabla \phi$. Lines of $\phi = \text{Constant}$ describe the velocity field, also called potential lines of flow. The velocity profile is defined with respect to orientation (x_1, x_2) as $d\phi = u' dx_1 + v' dx_2$, where $u' = \partial \phi / \partial x_1$ and $v' = \partial \phi / \partial x_2$. For the potential flow, it yields $dx_2/dx_1 = -u'/v'$, representing the potential lines that are by definition perpendicular to the streamlines. The streamlines are defined by the STREAM FUNCTION ψ , $u' = \partial \phi / \partial x_1 = \partial \psi / \partial x_2$. Note that irrotational flow is best defined by ϕ , while incompressible flow adheres to ψ ; for incompressible, irrotational flow both parameters apply. With the potential function, the flow definition reduces to one parameter instead of three velocity components: (u', v', w') . The VELOCITY POTENTIAL satisfies the LAPLACE EQUATION. The potential function for flow can be used to rewrite the Bernoulli equation as $\rho[(\partial/\partial t)\nabla \phi + (1/2)(\nabla \phi)^2] + \nabla P + \rho g \nabla x_3$, with P the pressure, ρ the local density, and g the GRAVITATIONAL ACCELERATION. The CIRCULATION (Γ_{circ}) for a free VORTEX in irrotational flow is described as $\Gamma_{\text{circ}} = \oint_C \vec{\omega}(\vec{r}, t) d\vec{r} = \oint_C \nabla \times \vec{v}(\vec{r}, t) d\vec{r} = \oint_C \nabla \phi(\vec{r}, t) d\vec{r}$, where $\vec{\omega}$ represents the vorticity (also see CAUCHY–RIEMANN EQUATIONS).

Potential head

[fluid dynamics] The head in FLUID DYNAMICS relates to the height of a LIQUID column; combining this with applied pressure, the potential head becomes the pressure head plus the elevation head. Expressed in ENERGY, the potential head is the potential energy per unit weight of the FLUID. The pressure head is the PRESSURE (P) per DENSITY (ρ): $P/\rho g$; the elevation head is height of the column y . For dynamic systems, the total head is the kinetic head plus the potential head, where the kinetic head (KH) is $KH = v^2/2g$, with v the flow velocity and g the GRAVITATIONAL ACCELERATION (see Figure P.146).



Expressed in energy the potential head is the potential energy per unit weight of the fluid. The pressure head is the pressure (P) per density (ρ): $\frac{P}{\rho g}$, respectively, the elevation head is height of the column: y . For dynamic systems the total head is the kinetic head plus the potential head, where the kinetic head (KH) is $KH = \frac{v^2}{2g}$, where v is the flow velocity and g the gravitational acceleration

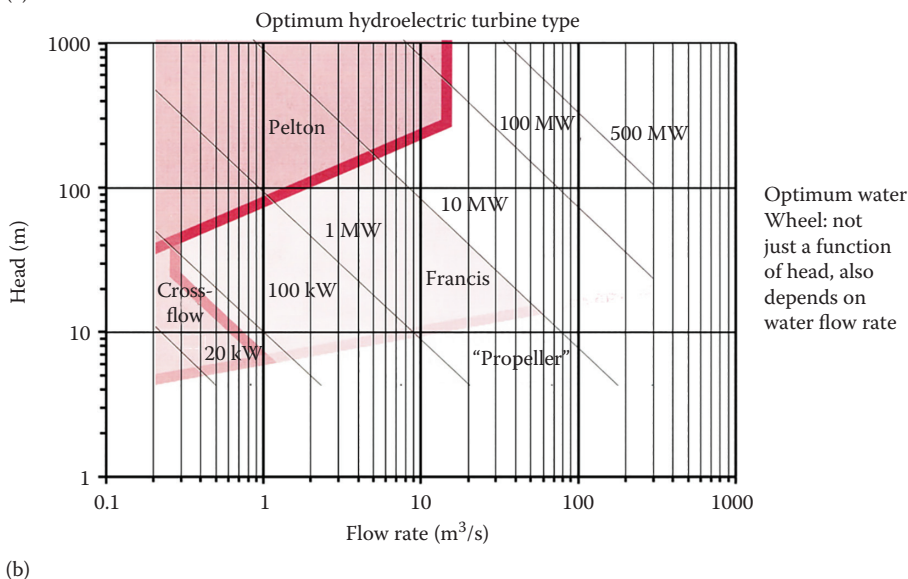
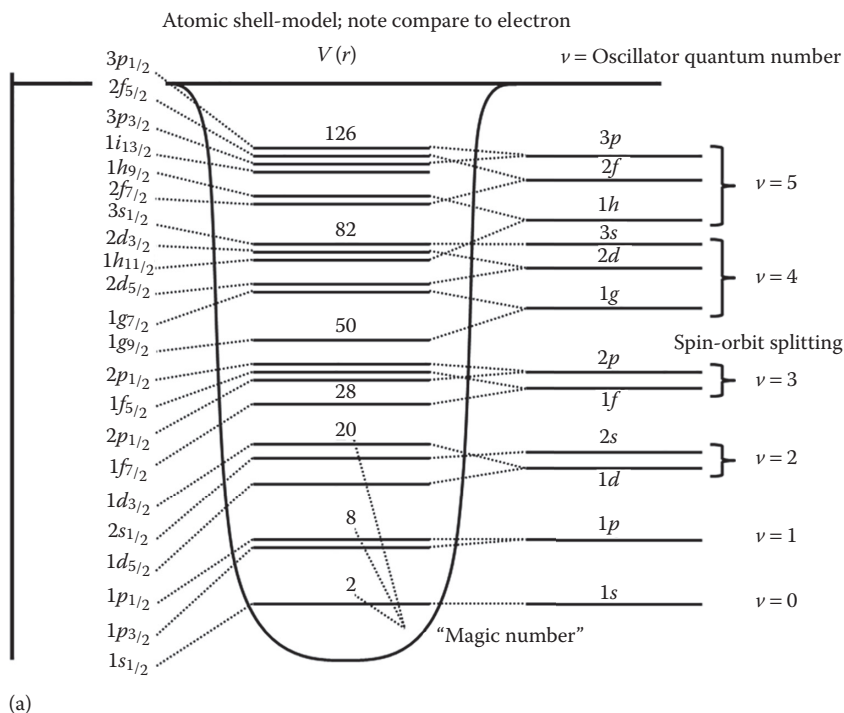


Figure P.146 (a,b) Potential head.

Potential well

[atomic, chemical, computational, nuclear, quantum, thermodynamics] In atomic PHYSICS, the ENERGY function for a nucleon in motion ("orbit") can be described by the SCHRÖDINGER equation, specifically in spherical coordinates only the radial part (r) remains: $-(\hbar^2/2m_0)(d^2u/dr^2) + \{[\ell(\ell+1)\hbar^2/2m_0r^2] + V(r)\} = Eu$, where $V(r)$ represents the potential that confines the nucleon, ℓ the ORBITAL QUANTUM NUMBER, u the (radial-) wavefunction, a polynomial function, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ PLANCK'S CONSTANT, m_0 the nucleon mass, and E the total energy of the process (kinetic and potential energy). Under the boundary conditions, u will be a finite polynomial when $r \rightarrow \infty$. For an INFINITE SQUARE WELL with radius R , the

potential function becomes $V(r) = 0$ for $r < R$; $V(r) = \infty$ for $r = R$. Alternatively, for a harmonic oscillator potential, the well is defined as $V(r) = (1/2)m_0\omega_0 r^2$ for $r < R$, where ω_0 is the oscillator angular frequency. More realistic cases are $V(r) = -V_0$ for $r \leq R$ and $V(r) = 0$ for $r > R$; alternatively, $V(r) = -V_0 + br + cr^2$ for $r \leq R$, a “rounded” or parabolic well (see Figure P.147).



For: $\ell = 0, 1, 2, 3, 4, 5$
The spectroscopic letters are assigned as follows:

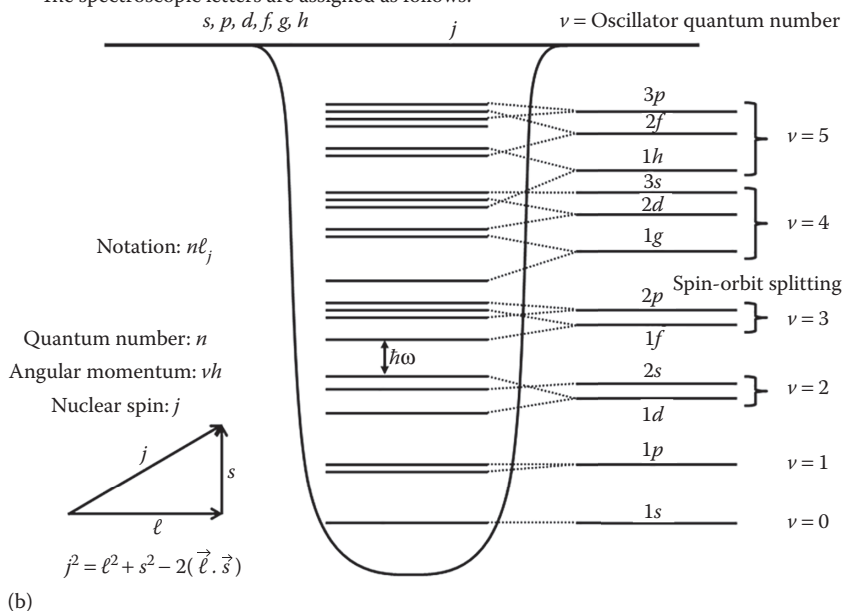


Figure P.147 (a,b) Potential well.

Potentiometer

[general] Variable, continuously adjustable RESISTOR. Generally, the potentiometer has three poles, between two the RESISTANCE increases (using the “center” connection as a reference) as the dial is turned clockwise; alternatively, switching the outer connectors makes the resistance decrease with increasing ANGLE (see Figure P.148).

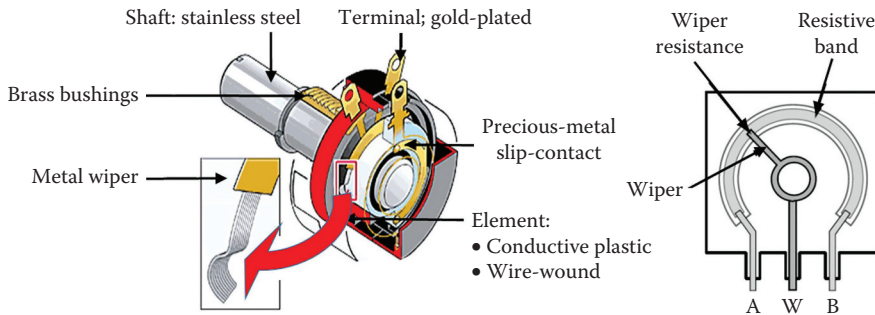


Figure P.148 Potentiometer.

Pound (lb)

[general] Unit of mass in the English unit system. One pound in SI UNITS equals 453.592 g. Most units in the system of measurements used in the United States are based on the British Imperial Units; however, in 1824 the British units were adjusted and there are now differences with the American units; for instance, the imperial gallon equals in SI units 4.54609 liters, whereas the US Gallon is 3.785411 liters.

Pound, Robert Vivian (1919–2010)

[atomic, imaging, nuclear] Scientist from Canada who was instrumental in the discovery and development of nuclear magnetic resonance imaging (MRI), while at Harvard University. The MAGNETIC RESONANCE work coincided with the independent work of the Swiss scientist FELIX BLOCH (1905–1983). He gained

additional fame with his experimental verification of general relativity concepts in the POUND–REBKA EXPERIMENT, in collaboration with Glen Anderson Rebka, Jr. (1931–) in 1959 (see [Figure P.149](#)).

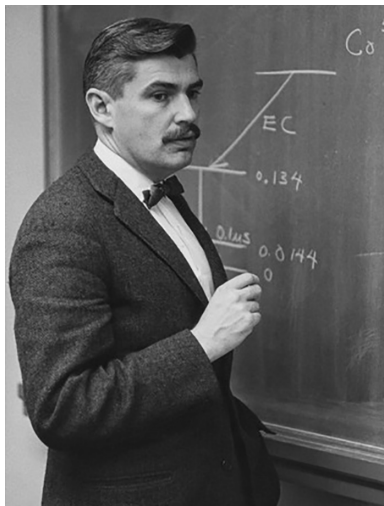


Figure P.149 Robert Vivian Pound (1919–2010). (Courtesy of Harvard University; Cambridge, MA. Image reference: UAV 605.270.5p, Box 7, Pound, Robert V., Harvard University Archives.)

Pound–Rebka experiment

[relativistic] Experimental verification of the special relativistic gravitational REDSHIFT and general relativistic blueshift under DOPPLER circumstances. The experiment performed by ROBERT VIVIAN POUND (1919–2010) and his student Glen Anderson Rebka, Jr. (1931–2015) in 1959 at Harvard University, Boston, MA, USA, combined the special relativistic redshift with the general relativistic blueshift. The special relativity ($\square$) Doppler shift is given by $\Delta v_{d,s} = \sqrt{\{1 + (v^2 \cos^2 \theta / c^2) / [1 - (v^2 / c^2)]\}} v_0$, where θ is the ANGLE between the relative velocity and the direction of MOTION of the source, v the relative velocity between the source and the observer, and c the speed of LIGHT. The blueshift predicted by general relativity resulting from gravitational influences ($\square_g$) is defined as $\Delta v_{d,g} = \sqrt{\{[1 - [2GM / (R + b) c^2]] / [1 - (2GM / R c^2)]\}} v_0$ $R \gg b$ $(MGb / R^2 c^2) v_0$, with G the gravitational constant, R the radius of curvature, and M the gravitational mass (i.e., Earth's mass). In superposition, this yields for the observation made by the detector: $\Delta v_{d,s,g} / v_0 = \sqrt{\{[1 + (v^2 \cos^2 \theta / c^2)] / [1 - (v^2 / c^2)]\}} \{1 - [2GM / (R + b) c^2] / [1 - (2GM / R c^2)]\}$. At the time, measuring the influence of the gravitational attraction from the top of the Harvard Jefferson building with a height of $b = 21.6$ m, resulting in a [measured] Doppler shift of $\Delta v_{d,s,g} / v_0 = 2.46 \times 10^{-15}$ for a 14 400 eV gamma ray produced by the Fe^{57} ISOTOPE, quite extraordinary.

Poussin, Baron Charles-Jean Étienne Gustave Nicolas de la Vallée (1866–1962)

[computational] Mathematician and physicist from Belgium. Charles de la Vallée Poussin is known for proving the Prime number theorem in 1896. Other work included the study of approximation theory (see [Figure P.150](#)).



Figure P.150 Baron Charles-Jean Étienne Gustave Nicolas de la Vallée Poussin (1866–1962).

Powell, Cecil Frank (1903–1969)

[atomic, nuclear] Scientist and physicist from Great Britain. Cecil Powell developed an innovative method using a photographic film to elucidate SUBATOMIC PARTICLES. The COSMIC RAYS at high altitude appeared to interact with the nuclei within the emulsion of the film. Discoverer of the π -meson, also known as the ; in 1946 (see [Figure P.151](#)).

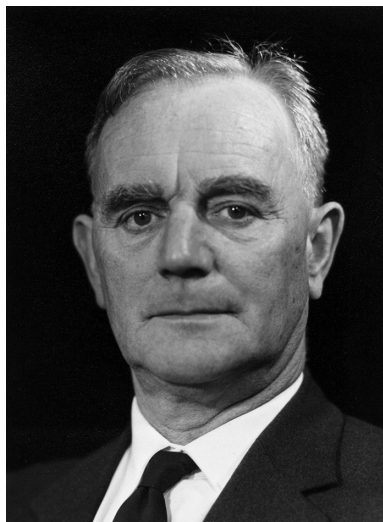


Figure P.151 Cecil Frank Powell (1903–1969).

Power (P)

[general, nuclear, thermodynamics] The TIME (t) rate of doing work ($W = \vec{F} \cdot \vec{d}$, the force F applied to move an object over a DISTANCE d): $P = dW/dt$; alternatively, the time rate of expenditure of ENERGY: $P = dE/dt$; units Watt (W). Also the force applied to a moving object in the direction of MOTION to maintain a constant velocity: $P = \vec{F} \cdot \vec{v}$, for instance to overcome resistive forces such as friction (sliding or rolling). In electrical applications, the power is the consumed or generated power from the CURRENT (I) and voltage (V), combined with OHM'S LAW with respect to RESISTANCE R (or more generally impedance Z), also referred to as apparent power $P = VI = V^2/Z = I^2Z$. Some examples of power equivalencies: $1(\text{BTU}/s) = 1054 \text{ W}$, $1 \text{ horsepower (HP)} = 745.7 \text{ W}$, $1(\text{gallon of oil/minute}) = 2.5 \text{ MW}$, and $1(\text{J/s}) = 1 \text{ W}$. The average power exerted by the human HEART can be estimated based on the contractile force, expressed as the ventricular PRESSURE (P) times the area of the aortic VALVE (A) multiplied by the flow velocity (v): $P = PAv$, which per beat is approximately 1.2 W . The power produced by the SUN (as a "NUCLEAR REACTOR") is approximately $4 \times 10^{26} \text{ W}$. The power produced by a waterwheel is on the order of $1\text{--}75 \text{ kW}$; the output depends on the head difference, flow rate, and the efficiency that is a function of the design and how well the water FLOW is "captured" to generate the torque. The power output of an undershot wheel is a function of the total area of the paddles that are exposed to flow (A), the flow velocity (v_{flow}), and the conversion efficiency (η_{conv}), expressed as $P = 100\eta_{\text{conv}}Av^3$; while for an "overshot" or breast shot wheel, the power results from the flow (Q) times the "bucket" size (volume V [i.e., the weight]; the head of the wheel [h_{head}]) as $P = 4\eta_{\text{conv}}QVh_{\text{head}}$. The efficiency is the result of the way water is captured as well as the electric GENERATOR attached or the mechanical gear to produce the work. The work can for instance be making paper, cutting wood, or lifting water (see Figure P.152).



Figure P.152 Waterwheel performing work and generating the power to perform other work.

Power cycle

[thermodynamics] Cyclic change of state in a thermodynamic system, such as a Carnot machine, Sterling cycle, OTTO CYCLE, Rankin cycle, DIESEL CYCLE, JOULE-BRAYTON CYCLE, cooling (refrigeration), or heating cycle, transforming ENERGY at a high- or low-temperature source to work. An additional power cycle is the LINDE-HAMPSON LIQUEFACTION CYCLE.

Power factor

[general] Real power consumption in an electrical circuit based on the PHASE shift (θ) between the current and the voltage resulting from the complex impedance: $P = VI \cos \theta$, where $\cos \theta$ represents the power factor for the alternating current circuit configuration. Note that $\cos \theta = 1$ for a purely resistive system.

Power law

[computational] Mathematical expression that has one parameter as a function of another parameter expressed to the order of a fixed or variable mathematical expression; for instance, in the most rudimentary form, $f(x) = ax^n$. The expression is the result of a causal dependency that influences the output by a certain MAGNITUDE or function. WIEN'S DISPLACEMENT LAW is one of many examples.

Power method

[computational] Computational mechanism of deriving eigenvalues for the solutions to a function. One interpretation is that the eigenvalues are the matrix ELEMENTS of a polynomial EXPANSION. The base matrix is used to derive the subsequent terms in an iteration method, substituting the last derived output to derive the subsequent term.

Power number ($N_p = c_{Np} (P_w/\omega_N^3 \rho L^5)$)

[energy, fluid dynamics, mechanics] Dimensionless number indicating the ratio of the net DRAG FORCE to the net INERTIAL FORCE pertaining to rotational systems, where $P_w = \Delta W/\Delta t$ (i.e., rate of change in WORK) is the POWER consumed or produced by the device, ω_N the rotational rate of change, c_{Np} a dimensional constant, ρ DENSITY, and L characteristic length. The Power number relates to MOMENTUM transfer in for instance agitators, pumps, and fans as well as power consumption.

Power spectrum

[acoustics, computational, optics] The ENERGY distribution per frequency range ("bin"), converting the SIGNAL distribution in a discrete format. This has particular value for the situation where there are limited frequencies, for example, harmonics only. The power spectrum generally can be derived by taking the FOURIER TRANSFORM. Note that the Fourier transform of a product is the convolution of the respective Fourier transforms and that the Fourier transform of a convolution is the product of the respective Fourier transforms.

Poynting, John Henry (1852–1914)

[electromagnetism, energy, general] Physicist from England. John Poynting was the theoretical resource behind the development of the general description of CONSERVATION OF ELECTROMAGNETIC ENERGY, in particular the flow of ELECTROMAGNETIC ENERGY and hence he was the eponym of the POYNTING VECTOR (see [Figure P.153](#)).

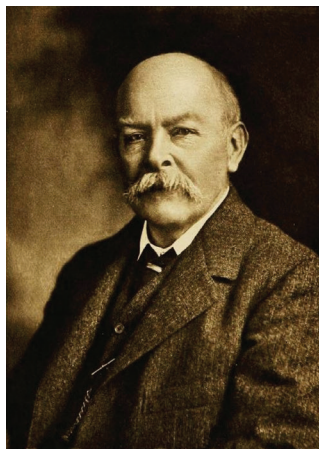


Figure P.153 John Henry Poynting (1852–1914).

Poynting correction

[thermodynamics] Expression used in the fugacity of LIQUIDS as a correction to LIQUID–VAPOR EQUILIBRIUM of a non-IDEAL GAS. The expression for the FUGACITY itself is $\pi_f(T, P) = \pi_f(T, P_0) \exp[\mu_f(T, P) - \mu_f(T, P_0)/RT]$, a slight deviation from the IDEAL GAS LAW: $PV = nRT$. The exponential term rewrites as $\exp[\mu_f(T, P) - \mu_f(T, P_0)/RT] = \exp\left\{\left(v_f/RT\right)[P_f(T, P) - P_{\text{sat}}(T)]\right\} \cong 1 + (v_f/RT)[P_f(T) - P_{\text{sat}}(T)]$, which is known as the Poynting correction. For ordinary media, the ideal gas law will be adhered to and the Poynting correction is close to unity, with the inherent condition that the fugacity is independent of the pressure and approximately equates $\pi_f(T, P) \cong P_{\text{sat}}(T)$.

Poynting vector ($\vec{S}$)

[atomic, electromagnetism, general] Vector indicating the direction and rate of passage through a unit area in the direction of propagation of the transport of ELECTROMAGNETIC ENERGY from the combined effects of an electric field ($\vec{E}$) and a MAGNETIC FIELD ($\vec{B}$), defined as $\vec{S} = (1/\mu_0)(\vec{E} \times \vec{B}) = \vec{E} \times \vec{H}$ (where $\vec{B}$ is the magnetic field measured in Tesla, and H is the MAGNETIC field expressed in N/mA), units: W/m^2 , where $\vec{S} = (\sqrt{\epsilon_0\mu_0}/4\pi)(\vec{E} \times \vec{B})$ is the Poynting vector and $c = \sqrt{\epsilon_0\mu_0}$ is the speed of LIGHT.

Praetorius, Michael (original name: Michael Schultheiß) (1571–1621)

[acoustics, mechanics] Composer and scientist from Germany. Praetorius used a particular musical analysis and organization and provided a rhythm “template” for sacred music in particular (cantus and hymns) (see [Figure P.154](#)).



Figure P.154 Michael Praetorius (1571–1621).

Prandtl, Ludwig (1875–1953)

[astrophysics, computational, fluid dynamics, thermodynamics] German mathematician and physicist that pioneered the development of a rigorous mathematical description of flow patterns and the influence of forces. He introduced the BOUNDARY LAYER in 1905. The boundary layer consists of a thin section of the flowing medium where the interaction with an object or other medium is expressed. The pioneering work by Archimedes (287–212 BC) only provided basics on statics for fluids. Additional anecdotal details of flow were presented by LEONARDO DA VINCI (1452–1519) by graphical interpretation. While LEONARD EULER (1707–1783) described the flow of a medium conceptualized as a CONTINUUM of small fluid ELEMENTS, the boundary effects were still not well defined in his days. The work of DANIEL BERNOULLI (1700–1782) was

more generalized that of Euler. The internal FRICTION with respect to fluid FLOW was introduced by CLAUDE-LOUIS NAVIER (1785–1836) in 1822 and later refined (presumably independently) by GEORGE STOKES (1819–1903) in 1845 to culminate in the Navier–Stokes equations for flow. He hypothesized that FLUID elements (Euler’s concept) directly in contact with a surface, which was moving at a different velocity, would experience attraction, and hence friction. The boundary layer is very different for a pure LIQUID in comparison to a colloid solutions (e.g., BLOOD), where the boundary effects will extend for the particulates. The body (or liquid) inside a flowing fluid will experience pressure on its surface and shear tangentially to the surface. The boundary layer will display a velocity profile that is dependent on the DISTANCE to the surface. Elaborating on Prandtl’s concept, PAUL RICHARD HEINRICH BLASIUS (1883–1970) expanded on the boundary layer problem in 1908 illustrating the separation of a boundary layer. Prandtl postulated a hypothesis on MIXING length for fluid-mechanic layers in 1925. The MIXING LENGTH (ℓ_m) is the distance along the shear layer at a surface, it takes for the fluid to reach the time average of an assumed sinusoidal velocity fluctuation starting out from turbulent, expressed as a function of the eddy viscosity η_T , the turbulent velocity (u_T), the velocity profile as a function of the STREAM FUNCTION (ψ) expressed as $U_y = \partial\psi/\partial y$; respectively $U_x = -\partial\psi/\partial x$, defined by $u_T \sim \ell_m |\partial U_y / \partial y| = \ell_m |\partial^2 \psi / \partial y^2|$ as a function of the distance to WALL ($\mathcal{Y}$). Far from the wall, the mixing length can also be approximated as a function of the von Kármán constant (κ_K) as $\ell_m = \kappa_K \mathcal{Y}$; however, this does not apply to the viscous sublayer. The known values for the mixing length for certain flow conditions are for instance for a regular emission JET: $\ell_m = 0.09 \ell_s$, where ℓ_s is the half-width of the shear layer; and for a circular jet: $\ell_m = 0.075 \ell_s$ (see Figure P.155).

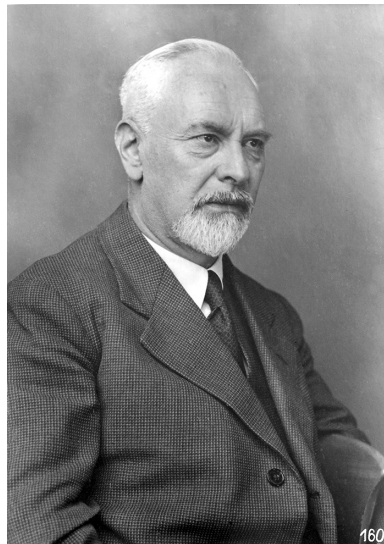


Figure P.155 Ludwig Prandtl (1875–1953).

Prandtl number ($Pr = (\eta/\alpha_{dif}) = c_p \eta / \kappa$)

[fluid dynamics] Dimensionless number expressing the ratio of the DIFFUSIVITY of momentum to thermal DIFFUSION, where η the KINEMATIC VISCOSITY, α the THERMAL DIFFUSIVITY, c_p the HEAT CAPACITY, and κ the THERMAL CONDUCTIVITY. This number shows the relation between HEAT TRANSFER and MECHANICS in both free and forced convection.

Prandtl–Meyer expansion

[fluid dynamics] Mathematical approach for SUPERSONIC FLOW, describing the ISENTROPIC expansion of a MACH WAVE through a series of Mach waves, where the CENTRAL wave portion is referred to as the Prandtl–Meyer expansion. The EXPANSION is divergent. This phenomenon is in particular related to the propagation

of a supersonic flow through a shock. Under these conditions, for normal flow the flow velocity normal to the shock is expected to increase; however, this will violate the SECOND LAW OF THERMODYNAMICS.

Prandtl–Meyer function

[fluid dynamics] Mathematical approach for SUPERSONIC FLOW, describing the ISENTROPIC expansion of a MACH WAVE through a series of Mach waves, where the central WAVE portion is referred to as the PRANDTL–MEYER EXPANSION. The Prandtl–Meyer function describes the flow expansion (fan type) as a function of the changing MACH NUMBER (Ma) as a function of ANGLE with the line of propagation: $dw/w = (dMa/Ma) + (dv_s/v_s)$, where $w = \sqrt{u_x^2 + u_y^2}$, u_x and u_y respectively the orthogonal flow-velocity components, $v_s = (\partial P / \partial \rho)_s$ the speed of sound, P the pressure, and ρ the local density. Expressed as a function of angle (Θ_{PM}) as the Prandtl–Meyer function: $\Theta_{PM}(Ma) = \sqrt{[(\gamma_b + 1)/(\gamma_b - 1)]} \tan^{-1} \left(\sqrt{[(\gamma_b + 1)/(\gamma_b - 1)][Ma^2 - 1]} \right) - \tan^{-1} \left(\sqrt{Ma^2 - 1} \right)$, where $\gamma_b = c_p/c_v$ is the ratio of SPECIFIC HEAT at constant pressure (c_p) to specific heat at constant volume (c_v). Generally, the parameter Θ_{PM} is listed in tabular form for the specific flow conditions.

Precession

[atomic, biomedical, mechanics, nuclear, quantum] Rotation of the axis of SPIN around a reference axis. The precession of the Earth's rotational axis is slow with a period of approximately 26 000 years. The rotation of the EARTH around the SUN provides the seasonal changes. A spinning top will “wobble” with its axis of rotation around the perfect vertical axis, normal to the gravitational plane. The angular velocity of the precession (ω_p) is the result of the MOMENT OF INERTIA (I_m), and the spinning ANGULAR VELOCITY (ω) around the object's axis of symmetry is expressed as $\omega_p = (d\phi/dt) = mgr/I_m\omega$, with r the DISTANCE from the intersect of the axis of rotation with the vertical reference axis (frame of reference; i.e., the pivot point) to the center of mass of the object in rotation with mass m , g the GRAVITATIONAL ACCELERATION, and ϕ is the ANGLE of rotation. Precession is used to give a GYROSCOPE a very stable frequency (*also see* LARMOR PRECESSION) (see Figure P.156).

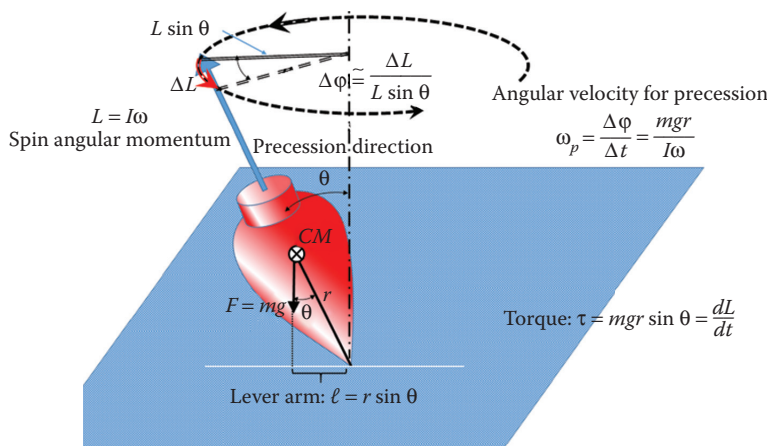


Figure P.156 The process of precession.

Pressure (P)

[biomedical, fluid dynamics, general, material, mechanics] Force (F) per unit area (A), expressed in all directions with equal MAGNITUDE: $P = \lim_{\Delta A \rightarrow 0} (\Delta F / \Delta A)$. Pressure has no direction and is hence a SCALAR quantity. The pressure of a LIQUID column with density ρ is directly proportional to the height (h) of the column above the point of interest, in addition to the pressure above the liquid from the GAS column (e.g., ATMOSPHERIC PRESSURE): $P = \rho gh + P_0$, where g is the GRAVITATIONAL ACCELERATION. Pressure can be used

to transfer force by means of changing the area as used in hydraulic systems. At the “critical pressure” in the PHASE DIAGRAM, the liquid phase and the VAPOR phase become identical. The units for pressure are PASCAL (Pa); colloquial use is ATMOSPHERE, or PSI (pounds per square inch) (see [Figure P.157](#)).

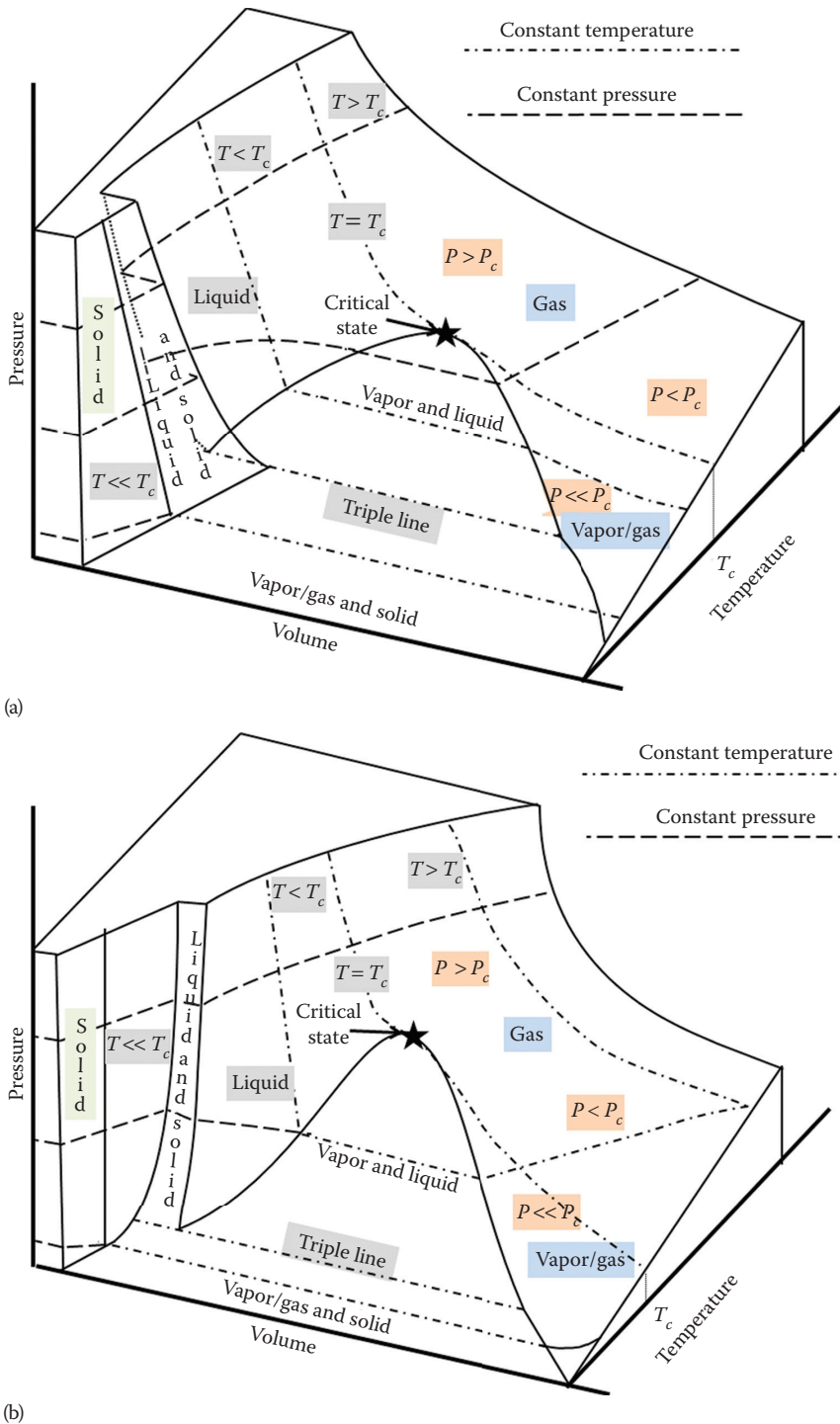


Figure P.157 Phase diagram including the influence of pressure on the physical conditions and state of a medium: (a) medium that has a lower density at temperature below the liquid–solid phase transition, for instance water, and (b) medium with decreasing density with decreasing temperature.

Pressure coefficient ($P_t = (P - P_\infty) / (1/2)\rho_\infty v_\infty^2$)

[astrophysics, fluid dynamics] Dimensionless number describing the ratio of the relative PRESSURES throughout a FLOW field to the KINETIC ENERGY density, also referred to as INERTIAL FORCES. In a FLUID FLOW field, every point will have a unique respective pressure coefficient. In the definition, the following parameters are used: P the pressure, P_∞ the pressure in the main body/volume of the fluid medium, ρ_∞ the bulk DENSITY, and v_∞ the VELOCITY of flow in the main part of the medium or main free flow. The pressure coefficient applies to flow over an AIRFOIL as well as BOUNDARY LAYER effects in fluid flow and RHEOLOGY.

Pressure cooker

[general] Device that is sealed in order to increase the PRESSURE (P) with respect to the ambient pressure in the closed VOLUME (V) with the direct consequence of an increase in temperature (T) of the boiling point of the LIQUID in the container based on the Boyle–Gay–Lussac law: $PV/T = \text{Constant}$. The concept of the pressure cooker was invented by DENIS PAPIN (1647–1712) in the late 1600s. For food, the chemical denaturation process increases by approximation over every 10°C, while the modern pressure cooker is designed to operate at approximately 121°C; the processing time is dramatically reduced. Alternatively, when living at high elevation, for instance in Denver, CO, USA, mile-high city (elevation approx. 1600 m), the cooking temperature is dramatically reduced under regular conditions, requiring longer cooking times. The autoclave is another example used for sterilization of medical equipment based on this principle (see [Figure P.158](#)).



Figure P.158 Pressure cooker.

Prévost, Pierre (1751–1839)

[general, nuclear, thermodynamics] Scientist and clergyman from Switzerland with a minor interest in law. Primarily known for his contributions on heat (thermodynamics) and MAGNETISM (see [Figure P.159](#)).

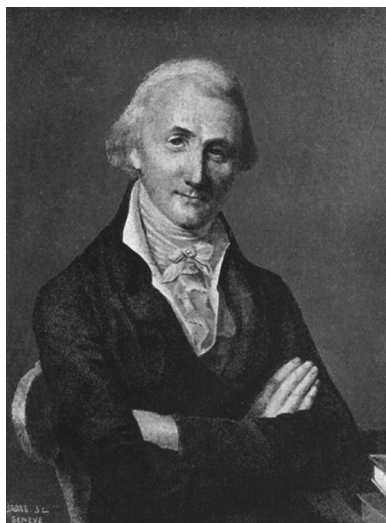


Figure P.159 Pierre Prévost (1751–1839). (Courtesy of *Journal Officiel Illustré De L'Exposition Nationale Suisse* Genève 1896.)

Prévost theory of heat exchange

[atomic, nuclear] Matter at constant temperature is in perfect equilibrium, proposed by PIERRE PRÉVOST (1751–1839) in 1791.

Priestley, Joseph (1733–1804)

[chemistry] English chemist and theologian attributed with the discovery of the colorless and reactive GAS oxygen (O_2 ; although it was named by the French chemist ANTOINE LAURENT LAVOISIER [1734–1794]). Priestley's breakthrough observation was that AIR was not a single substance but a mixture of elementary components,

that is, gasses, as published in 1774. Additionally, Priestley invented several items such as the rubber eraser and carbonated water (see [Figure P.160](#)).



Figure P.160 Joseph Priestley (1733–1804) in 1794. (Courtesy of Ellen Sharples [1769–1849]. Scan of a print. Original at the National Portrait Gallery, London, England.)

Primary colors

[general] Based on human perception the following three colors can be used to make up in access of 10 million colors as defined by the base colors RED, green, and blue (RGB), as outlined by the CIE CHROMATICITY diagram. The RGB mechanism is for instance applied to monitors as well as digital cameras. The documented first observation of the eye's response to three colors was by THOMAS YOUNG (1773–1829) in the early 1800s (see [Figure P.161](#)).

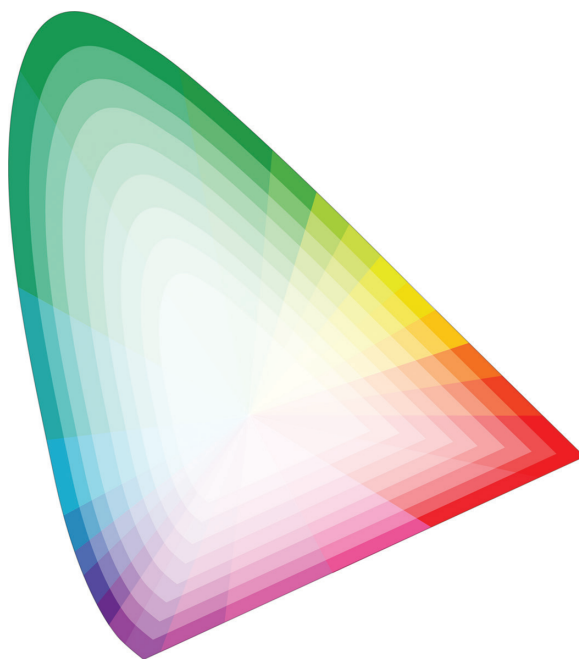


Figure P.161 Color chart as defined by the CIE 1931 (Commission internationale de l'éclairage; "International Commission on Illumination") with primary colors defining the corners of the map.

Primary cosmic ray particles

[atomic, nuclear] Various SUBATOMIC PARTICLES reach the Earth's ATMOSPHERE from outer space, ranging from protons (~89%) to helium nuclei (10% of total), up to uranium nuclei (1% heavy nuclei). In the upper atmosphere, these particles will collide and generate reactions, primarily generating pions.

Primary electron

[solid-state] The electron ejected from an ATOM by an initial ionizing event, as caused by a PHOTON or BETA PARTICLE.

Principal moments

[atomic, mechanics, solid-state] The MOMENT OF INERTIA associated with a rigid molecule. The MOLECULE has three principal moments, which follow from the diagonalization of the moment of inertia matrix:

$$I = \begin{bmatrix} \sum_i m_i (y_i^2 + z_i^2) & -\sum_i m_i x_i y_i & -\sum_i m_i x_i z_i \\ -\sum_i m_i y_i x_i & \sum_i m_i (x_i^2 + z_i^2) & -\sum_i m_i y_i z_i \\ -\sum_i m_i z_i x_i & -\sum_i m_i z_i y_i & \sum_i m_i (x_i^2 + y_i^2) \end{bmatrix} = C \begin{bmatrix} I_A & 0 & 0 \\ 0 & I_B & 0 \\ 0 & 0 & I_C \end{bmatrix},$$

where in case all three moments are equal the molecule is referred to as a spherical rotor (e.g., CH₄); in case only two are equal the molecule is a symmetric rotor (e.g., CH₃CL); and if all three are different the molecule is an asymmetric rotor (e.g., H₂O).

Principal plane

[mechanics] The plane to which the stress in the direction of the normal is at extreme (maximal/minimal).

Principal quantum number

[atomic, nuclear] QUANTUM NUMBER defining the binding states of electrons: n . For the ENERGY states of the electron with mass m_e and charge $e = 1.60217657 \times 10^{-19} \text{C}$, this provides for a NUCLEUS with cumulative proton charge Z : $E_n = -m_e e^4 Z^2 / 8 \epsilon_0^2 h^2 n^2$, with $\epsilon_0 = 8.85419 \times 10^{-12} \text{C}^2/\text{Nm}^2$ the permittivity of free space and $h = 6.62606957 \times 10^{-34} \text{m}^2 \text{kg/s}$ PLANCK'S CONSTANT. In the Bohr model, this yields $E_n = -(13.6/n^2) \text{eV}$ for each level, $n = 1, 2, 3, \dots$. Note that in some cases, the "REDUCED MASS" need to be used: $m' = m_e M / (m_e + M)$, where M is the total mass of the protons.

Principal stress

[biomedical, mechanics] Stress in the PRINCIPAL PLANE.

Principia of Newton

[general] Published in 1687 by SIR ISAAC NEWTON (1642–1727) on the laws of MOTION as well as the wave-particle duality of light: the first law is the LAW OF INERTIA; the SECOND LAW is the force law; and the third is the law of reciprocity. The WAVE characteristic of LIGHT was not readily accepted for almost 150 years, until resurrected by THOMAS YOUNG (1773–1829) and AUGUSTIN FRESNEL (1788–1827).

Principle of complementarity

[general] Fundamental principle that applies to quantum-mechanical phenomena, specifically with respect to the BOHR ATOMIC MODEL as described by Niels Henrik David Bohr (1885–1962) in 1913. The principle of

complementarity states that in quantum-mechanical phenomena the outcome of experimental observations is directly correlated to the instruments used to analyze the mechanism of action, which is related to the Schrödinger “cat” (both alive and dead) as well as the double slit that appears to describe that a single PHOTON can be in two place simultaneously. Based on the “complementarity,” the basic mathematical formalisms of QUANTUM MECHANICS were developed autonomously by both WERNER HEISENBERG (1901–1976) and ERWIN SCHRÖDINGER (1887–1961) in 1926. The consequence of the principle of complementarity was the Copenhagen interpretation of quantum mechanics.

Principle of conservation of mass

[fluid dynamics] See CONSERVATION OF MASS.

Principle of corresponding states

[fluid dynamics, solid-state] Theorem introduced by JOHANNES DIEDERIK VAN DER WAALS (1837–1923) in 1873 concerning the similar (identical) behavior of all fluids at the scaled parameters for temperature ($T_s = T/T_c$), volume ($V_s = (V/V_c)$), and pressure ($P_s = P/P_c$) with the same compressibility factor $Z_c = P_c V_c / n_c k_b T_c$, which is taken at the critical point ($\square_c$), where n_c is the number of particles (molecules/atoms) and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ is the Boltzmann coefficient. The fluids can be considered to act under the same deviation (adjustment/offset) from the IDEAL GAS LAW, as if they are ideal gasses.

Principle of highest entropy

[thermodynamics] A system that is in stable equilibrium will have a higher entropy than any other system state with the same constituent and ENERGY parameters. Alternatively, this configuration will have the lowest energy.

Principle of least action

[general, mechanics] In follow-up on NEWTONIAN MECHANICS, the concepts of equation of MOTION can be derived from perturbations to stationary situations. The least action principle considers the path of an object with mass m and potential ENERGY $U(\vec{r})$ that leads from beginning to end as a function of time (t), instead of the start and end points, assigning a SCALAR that defines the action as a function of location ($\vec{r}$): $S[\vec{r}(t)] = \int_{t_1}^{t_2} [(1/2)m\dot{\vec{r}}^2 - U(\vec{r})]$, where the path holds an extremum of the “action” performed, $\dot{\vec{r}} = d\vec{r}/dt$.

Principle of lowest energy

[thermodynamics] A system that is in stable equilibrium will have the lowest ENERGY in comparison to the identical system in any other state.

Principle of relativity

[general] Relativity is subdivided into general relativity and special relativity; see the respective descriptions for additional details. The concepts of relativity were introduced by ALBERT EINSTEIN (1879–1955) in 1905. Based on Newtonian physics, as introduced by SIR ISAAC NEWTON (1642–1727), GRAVITY was constant, but with new knowledge adjustment had to be made. The traditional gravitational potential (ϕ_G) linked by the Poisson equation to gravity was $\nabla^2 \phi_G = \nabla \cdot \nabla \phi_G = [(\partial^2 / \partial x^2) + (\partial^2 / \partial y^2) + (\partial^2 / \partial z^2)] \phi_G = 4\pi G \rho$, where ∇^2 is the Laplace operator, G is the gravitational constant, and ρ is the density of MATTER, which was changed to include a time-dependent aspect as the d'Alembertian operator ($\square_{d'A}$): $\square_{d'A} \phi_G = \left\{ \left[(1/c^2)(\partial^2 / \partial t^2) \right] + \nabla^2 \right\} \phi_G = 4\pi G \rho$, where $c = 2.99792458 \times 10^8 \text{ m/s}$ is the speed of LIGHT. The first postulate by Albert Einstein with respect to relativity is that all laws of PHYSICS are valid and identical for observers moving in uniform motion, even though they may be in separate reference frames. The second postulate states that the speed of light, in free space, will be constant and independent of the MOTION of the source. Relativity is split between the fields of “classical physics” and “modern physics.” Relativistic

concepts are the result of Einstein's postulate that gravity is curved, in both space and time, as part of general relativity under classical physics, while the postulates of Einstein are part of modern physics.

Prism

[optics] Transparent body with specifically two surfaces at an ANGLE. The medium of the optical body will have an index of refraction different from the ambient medium, generating refraction at both surfaces, resulting in an angular deviation from the ray incident with an angle to the normal on the first surface, incident in the plane outlined by the normal and the axis of the plane normal to the line mating the adjoining plane (see Figure P.162).

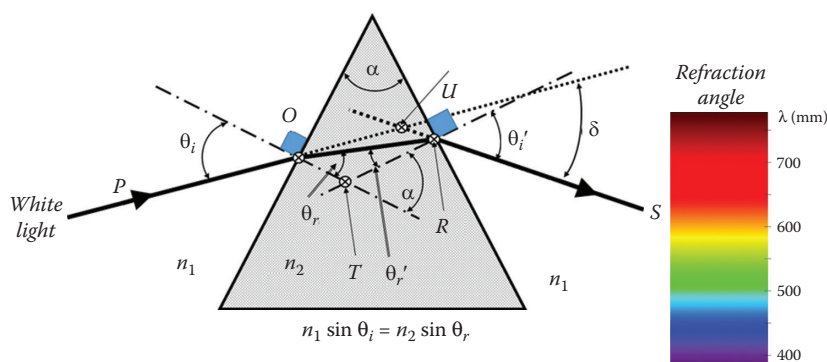


Figure P.162 Prism- and color-based refraction (i.e., wavelength).

Probability

[atomic, computational, nuclear, thermodynamics] Branch in mathematical analysis that studies the likelihood of the occurrence of an event. The probability is the specific outcome divided by the total number of events. The probability ranges from 0 to 1, or respectively 0% to 100% likelihood. Specifically, with respect to other events in a probability distribution. The probability is often weighed against a null hypothesis, as proposed in 1931. The null hypothesis is the definition that the event is related to the most-likely phenomenon, at “zero change,” in contrast to the “alternate hypothesis” that everything is different. The most well-known probability is for a coin toss; “heads–tails,” with 50% probability for “heads,” provided a large enough number of tosses are performed. Probability is frequently used to prove or disprove a hypothesis, when the number of occurrences yields a fit less than a certain “ p -value,” chosen based on preferences: $p < 0.05$, $p < 0.01$, $p < 0.005$; the smaller the p -value the better the argument that the alternate to the null hypothesis is *rejected*; hence the event is true in comparison to a standard. The p -value is an indication of the significance of obtaining a test value with statistical MAGNITUDE at least as high in comparison as actually observed, under the assumption that the null hypothesis is true. Alternatively, the p -value is an indication of getting a different answer than the null hypothesis; hence a small p -value means low likelihood and null hypothesis stands correct. Probability can be distributed over opportunities. Several probability distributions are available from a mathematical foundation: POISSON DISTRIBUTION, NORMAL DISTRIBUTION, GAUSSIAN DISTRIBUTION, multinormal distribution, iniform distribution, delta function, bionomial distribution, Bernoulli distribution, gamma distribution, Student's t -distribution, and several more. Note that the “normal” distribution is not the most likely probability distribution for every phenomenon; the name does

not represent the causality. The choice of distribution has to do with the sample size, the phenomenon, and the representation of “outliers” (failed events) (*also see* **BAYESIAN ANALYSIS**) (see [Figure P.163](#)).



Figure P.163 Concept of probability.

Probability, theory of

[computational, mechanics]: fundamental concept of **PHYSICS** in the description of the opportunities and chances for an event or **ENERGY** configuration the form and the path the process will follow based on the available options of energy distribution as initially described by **BLAISE PASCAL** (1623–1662) and **PIERRE DE FERMAT** (1601–1665). Theoretical analysis pertaining to random phenomena. The nondeterministic events in physics and engineering that are either discrete, unique in occurrence, or have a pattern of evolution that does not follow a path that can be defined by strict conditions (i.e., **STOCHASTIC PROCESS**). The probability theory dates back to the teachings of **PIERRE DE FERMAT** (1601–1665), **BLAISE PASCAL** (1623–1662), and **PIERRE-SIMON MARQUIS DE LAPLACE** (1749–1827) with further refinements by for instance **ALEKSANDR MIKHAILOVICH LYAPUNOV** (1857–1918). The formulation of these events has its primary foundation in statistical methods. In biomedical aspects, this relates to **BAYES' THEOREM**. The other side of **PROBABILITY** is in **QUANTUM MECHANICS** and **HEISENBERG'S UNCERTAINTY PRINCIPLE**. Examples of stochastic processes are **BROWNIAN MOTION**, thermal collisions, and the **DOUBLE-SLIT EXPERIMENT**. An additional feature of a wave representation of an object in **MOTION** provides a mechanism of outlining the probability of an objects location, in particular the location of an electron. This provides a concept known as the probability flux. The probability **FLUX** is associated with solutions to the **SCHRÖDINGER WAVE EQUATION**, outlining the momentum associated with the eigenvalues of the solutions that can be used to define a “particle density” (*also see* **PROBABILITY**).

Projectile

[general, mechanics] Object moving in two or three dimensions. **GALILEO GALILEI** (1564–1642) was one of the first documented scientists that recognized that the projectile **MOTION** can be segregated in two independent motions: horizontal and vertical. The horizontal motion is the result of the applied force,

whereas the vertical motion is defined by gravitational interaction. A ballistic projectile is an object that is launched to target something (see [Figure P.164](#)).



Figure P.164 Ballistic projectile.

Prompt neutron

[atomic, nuclear] During NUCLEAR FISSION, in excess of 99% of NEUTRON are emitted within a “brief” delay (10^{-12} s), with respect to the FISSION event and are referred to as prompt neutrons. Several neutron may be emitted as long as minutes later and these are called delayed neutrons. However small the fraction of delayed to prompt neutron may be, the delayed neutrons form an essential control mechanism for the nuclear reaction.

Propeller

[fluid dynamics] Circular symmetric three-dimensional mechanical design with discrete sections that are twisted to perform a specific fluid dynamic function during rotation around the central axis. Blades on a propeller will convert rotational MOTION into thrust, either moving the object the propeller is attached to or making the propeller rotate under an applied flow to for instance generate ELECTRICITY. Propellers are found on airplanes and boats in particular for PROPULSION, and on wind turbines for generating electrical power. The THRUST (T_b) provided by a propeller is a function of the ANGLE of the blade (ϕ) and the LIFT of the blade from the plane of attachment (α) as well as the ENERGY from the torque on the blade as a function of location (L) and shear energy over the blades (w , at widest segment): $T_b = dL \cos(\phi + \alpha) - dw \sin(\phi + \alpha)$, with associated TORQUE (τ_b), as a function of the radius to the axis (r), approached by discrete incremental steps over the radial DISTANCE along the length of the propeller: $\tau_b = r \{ dL \cos(\phi + \alpha) - dw \sin(\phi + \alpha) \}$, where $dL = (1/2)\rho |\vec{v}_e|^2 c^* C_\ell dr$ (with ρ the fluid density, $\vec{v}_e$ the exit flow velocity, c^* a fractional factor (representative of the performance efficacy), C_ℓ the surface) and $dw = (1/2)\rho v_e^2 c^* C_d dr$ (with C_d the surface area carved out by the rotating propeller). Propeller efficiency (η_{propel_p}) with respect to propulsion is the ratio of the kinetic energy of the flow ($P_{\text{flow}} = \dot{m}[(u_e^2/2) - (u_0^2/2)]$), where $\dot{m} = \partial m / \partial t$, $u_e = \vec{v}_e \cdot \vec{n}$ the normal flow velocity through the propeller, and u_0 the background FLOW velocity (i.e., flight velocity), and with respect to the propulsive power ($P_{\text{propel}_p} = \text{thrust} \times \text{flight velocity}$): $\eta_{\text{propel}_p} = 2[1 + (u_e/u_0)]^{-1}$, which is equivalent to the efficiency of a jet engine. Alternatively, the FLUID dynamic efficiency for a GENERATOR is rather complex, depending on the fluid FLOW (e.g., water, AIR, combustion), and only the power (P_{turbine}) and efficiency (η_{turbine}) for a wind TURBINE is provided. The power of a wind turbine in approximation is a function of the rotor swept area (A_{swept}), the density of the air (ρ), the wind velocity (v_w), the generator efficiency ($\eta_{\text{generator}}$), the gear transfer efficiency (η_{gear}), as well as a general coefficient of performance (c_{perf}): $P_{\text{turbine}} = 0.5\rho A_{\text{swept}}\eta_{\text{gear}}\eta_{\text{generator}}\eta_{\text{perf}}v_w^3$; the efficiency is now: $\eta_{\text{generate}_p} = (P_{\text{out}}/P_{\text{turbine}}) = (VI/0.5\rho A_{\text{swept}}\eta_{\text{gear}}\eta_{\text{generator}}\eta_{\text{perf}}v_w^3)$, where P_{out} is the electrical output power, based

on CURRENT (I) and voltage (V), which requires corrections for PHASE losses (the generator is a multiphase generator, ideally all need to be in phase), specifically when multiple generators are connected together. Wind turbines generally do not effectively generate electricity at wind velocity below 8 km/h (see [Figure P.165](#)).



Figure P.165 Range of propellers used for the generation of electricity. Specialty propeller designs for wind turbines. (Courtesy of Helix Wind.)

Propulsion

[general, mechanics, thermodynamics] Push forward, mechanism of THRUST that makes an object move, operationally based on NEWTON'S THIRD LAW. Propulsion is specifically associated with JET engines, whereas PROPELLER engines provide propulsion as well. The force is exerted in several directions, while a remaining net force exerted on one surface that will result in a MOTION of that surface with radial forces canceling out and the force in the direction opposite to the surface in motion discarded. Thrust is a force (F), specifically the change in momentum ($p = mv$, where m is the mass and v the velocity; note that the combustion mass changes over time as well: $\dot{m} = dm/dt = \rho v A$ as a function of DENSITY (ρ), and cross-sectional area (A)) over time (t): $F = (dp/dt)$. The propulsion of a jet engine can be expressed as $F_T = \dot{m}_e v_e - \dot{m}_0 v_0 + (P_e - P_0) A_e$, where the respective subscripts denote the exit ($\square_e$) and ambient ($\square_0$) conditions, and the PRESSURE (P) plays a role as well. The rocket engines for the space shuttle for instance produce 1.8 MN thrust. The propulsion from a propeller engine with propeller area (A_{prop}) can be expressed as $F_T = 2\rho A_{\text{prop}} (v_\infty + v) v$, where v_∞ is the fluid velocity, v the velocity "induced" to the medium (e.g., increase in AIR flow, water flow), and ρ the FLUID density (also see PROPELLER) (see [Figure P.166](#)).



Figure P.166 Water propulsion.

Proton

[atomic, nuclear] Nuclear particle (BARYON, HADRON) with a positive ELECTRIC CHARGE equal numerically to the charge of the electron and having a mass of $m = 1.673 \times 10^{-27} \text{ kg} = 1.007575 \text{ mu}$ and charge $q = +1.60217657 \times 10^{-19} \text{ C}$. FERMION with SPIN of one half unit: $s = (1/2)\hbar = (1/2)(h/2\pi)$ ($h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ PLANCK'S CONSTANT). The PROTON is composed of three quarks, two quarks in the “up” direction and one in the “down” orientation (classification: uud). Theoretically, a proton can DECAY with emission of a PION or positron; however, experimentally to date there is no evidence that a proton will decay, and the lifetime of a proton has been established at 10^{31} years.

Prout, William (1785–1850)

[atomic, biomedical, nuclear, thermodynamics] Physician, chemist, and scientist from Great Britain. William Prout proposed that based on the current knowledge of the periodic table all ELEMENTS were composed of constituents resembling the HYDROGEN ATOM, called “protyle” by William Prout, although never observed by him. His concepts of nuclear structure predate the Bohr model and verified detection of specific particles by almost one hundred years. Additionally, Prout made statements about the biological system, such as the METABOLIC ACTIVITY, that could not be verified at the time but hold great value for current biological knowledge. The unit of NUCLEAR BINDING ENERGY was named after him, the Prout, which is $(1/2)$ binding energy of the DEUTERON = 185.5 keV. He also made several contributions to the theoretical description of HEAT TRANSFER. Based on William Prout's rudimentary but essential contributions to the understanding of the nuclear construction, the discovery of the PROTON was named in his honor by ERNEST RUTHERFORD (1871–1937) during its discovery in 1920 (see [Figure P.167](#)).

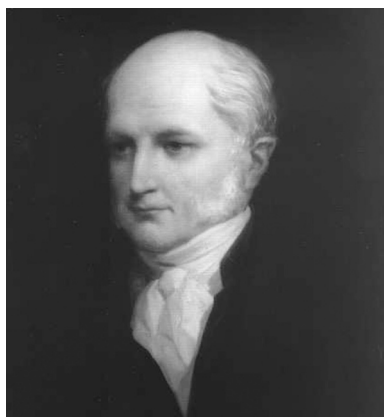


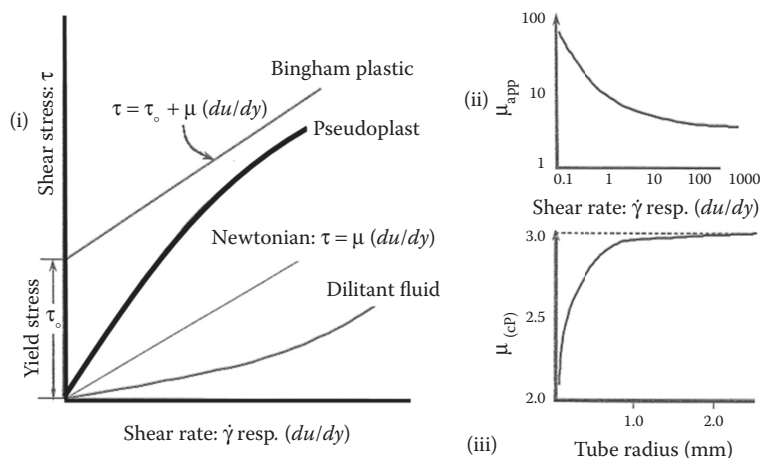
Figure P.167 William Prout (1785–1850).

Prout's hypothesis

[nuclear] Proposition that all chemical ELEMENTS are constructed with base building blocks resembling the helium ATOM, referred to as “protyle.” Suggested by WILLIAM PROUT (1785–1850) in 1815. Using the protyle as the building block for ISOTOPE, atomic mass description is accurate within 1%.

Pseudo plastics

[biomedical, fluid dynamics] **SHEAR-THINNING FLUID**, FLUID that decreases in **SHEAR FORCE** with increasing flow velocity. The associated viscous phenomena also decrease with a reduction in viscosity per se, in contrast with a **NEWTONIAN FLUID** or dilatant fluid (see [Figure P.168](#)).



Alterations in viscosity: (i) Non-newtonian fluids, (ii) apparent viscosity, and (iii) the Fahraeus–Lindqvist effect.

(a)



(b)

Figure P.168 (a) Shear-thinning and (b) slurry, liquid manure.

Psychrometry

[thermodynamics] **Energetic study of MOIST AIR**. The mixture of air and water VAPOR in the Earth's **ATMOSPHERE** may generally be considered as an **IDEAL GAS**, not accounting for foggy conditions. Also referred to as **hydrometry**. The graphic outline of the relationship between **RELATIVE HUMIDITY**, specific humidity, molar fraction, and total mass of water vapor is represented by a psychrometric chart, also known as **MOLLIER CHART** (see **MOLLIER CHART**).

Ptolemaeus, Claudius (approximately 90–168 AD)

[astrophysics/astronomy, geophysics] Astronomer, mathematician, and geophysicist from Greece. Author of a comprehensive work on all the information available in his time on the SOLAR SYSTEM and astronomical phenomena: *Μεγάλη Σύνταξις* (i.e., summary), mostly based on the work of HIPPARCHUS (190–125 BC). He is also known for his detailed tabulation of trigonometrical data with greater detail and more elaborate incremental steps than most current mathematical handbooks (also **PTOLEMY**) (see [Figure P.169](#)).



Figure P.169 Ptolemy (approximately 90–168 AD), rendering produced in the early sixteenth century.

Ptolemy (approximately 90–168 AD)

[general, optics] Scientist from Greece. Ptolemy described the ANGLE of incidence and refraction for water and made attempts to relate them mathematically (also **CLAUDIUS PTOLEMAEUS**).

p-type doping

[atomic, electronics, general] Intrinsic SEMICONDUCTORS that have had impurities introduced are considered to be doped, impurities consisting of foreign atoms into a crystal lattice structure. The crystal lattice structure provides the conduction and ENERGY platform for a stable structure. Certain semiconductors have VALENCE electrons that can easily be moved to the CONDUCTION BAND, sometimes spontaneously under slightly elevated temperatures. The ultimate release of the conduction electron (electron deficiency) creates a “hole” in the semiconductor lattice that can travel as if it were a POSITIVE CHARGE, hence the nomenclature *p*-type doping; positive. Introduction of an impurity with three valence electrons generally results in the formation of a “hole” in the lattice. The lattice may for instance consist of germanium or silicon. The FERMÍ LEVEL for intrinsic semiconductor materials is generally in the middle between the VALENCE BAND and the conduction bands in the energy level diagram. For the *p*-TYPE SEMICONDUCTOR, the valence band will have “hole energy” whereas the conduction band comprises “electron energy.” Joining a *p*-type semiconductor with an *n*-TYPE SEMICONDUCTOR creates a PN-JUNCTION that can be influenced to modulate electron transmission between the two semiconductor materials, creating on an elementary level a DIODE. The addition of more *n*-type and/

or *p*-type junctions will form transistors and more complex integrated circuit designs (*also see N-TYPE, DIODE, and TRANSISTOR*) (see [Figure P.170](#)).

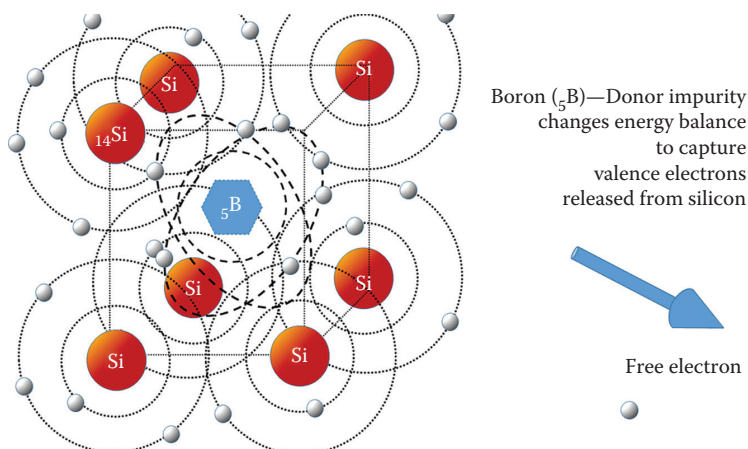


Figure P.170 *p*-type doping, semiconductor energy configuration.

p-type semiconductor

[electronics, general] Semiconductor material with an electron deficiency, permanently imbedded “holes” (*see P-DOPING*) (see [Figure P.171](#)).

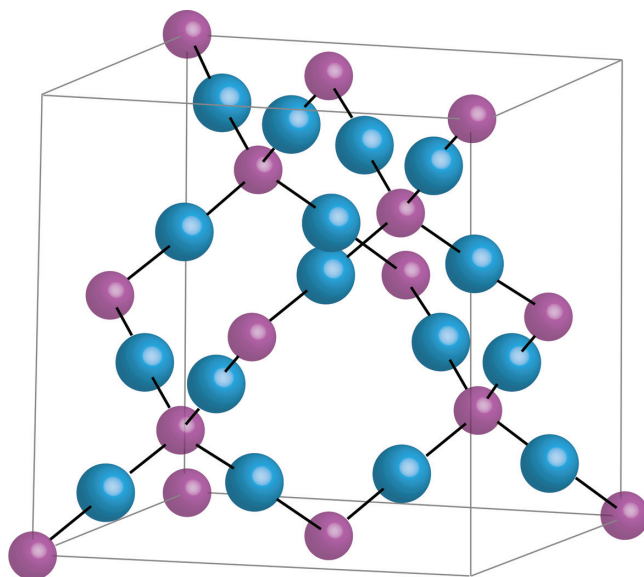


Figure P.171 Silicon oxide crystal design as the basis for certain semiconductor platforms.

Pulley

[general, mechanics] System of wheels with v-shape or u-shape channel along the outside track of the wheel to fit a belt or rope (chain) to run over the outside circumference. The pulley acts as a force multiplier depending

on the number of up–down loops used for hoisting a mass upwards, or alternatively for a horizontal force and direction. Hanging a mass on the pulley and attaching a rope to a location above the pulley will require half the force applied to raise the object when applying tension on the free distal end of the rope. This is due to the fact that both ends of the rope have equal tension, combinedly yielding the gravitational force on the object; thus the free end only has half the tension, requiring half the force (see [Figure P.172](#)).

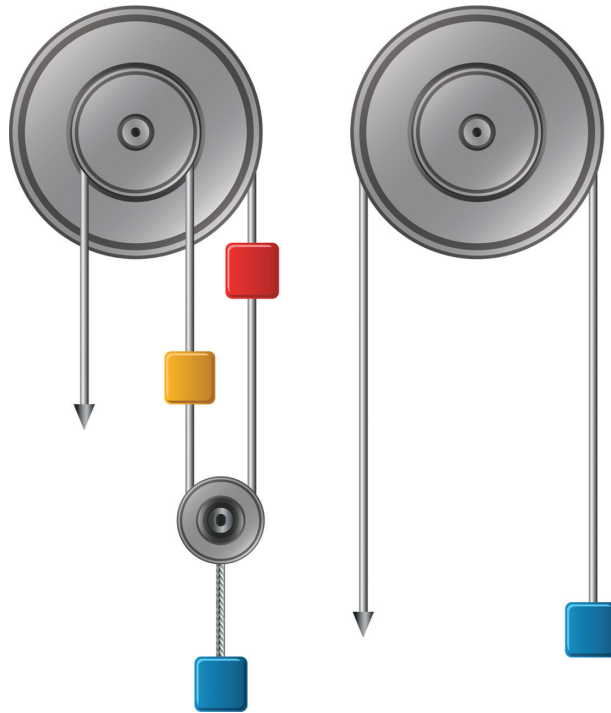


Figure P.172 Pulley.

Pulmonary system

[biomedical, fluid dynamics] Biological system consisting of the lungs and vasculature, providing RESPIRATION function. The GAS exchange in the lungs between AIR and BLOOD is based on HENRY'S LAW that states that the gas volume, and therefore the concentration ($[Gas]$) dissolved in a LIQUID is directly proportional to its partial PRESSURE (P), defined as $[Gas] = K_{sol}P$, where K_{sol} is a solubility constant. The thin alveolar and pulmonary CAPILLARY walls provide a minimal BARRIER, allowing for swift DIFFUSION of oxygen and carbon dioxide, yielding a rapid equilibrium for the respective partial pressures of the constituents. This equilibration diffusion is described by Fick's law, relating the rate of diffusion to the concentration gradient as well as surface area for gas exchange, while being inversely related to the thickness of the WALL of the exchange surface; alveolar membrane. Pulmonary CIRCULATION is the flow from the HEART to the lungs and back. One specific biomedical complication in FLUID DYNAMICS is a pulmonary EMBOLISM, a blockage due to plaque or blood clot that reduces the flow to zero. At this point, the local VENTILATION/PERFUSION ratio becomes large, while reducing it for the

“healthy” part of the lung. The remaining functional perfused segment of the lungs will result in large arterial to alveolar P_{O_2} , difference with an associated increase in PHYSIOLOGICAL DEAD SPACE (see [Figure P.173](#)).

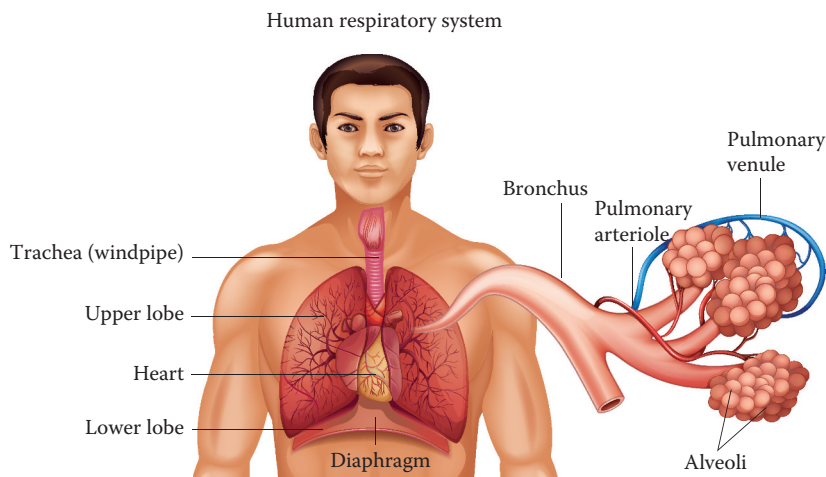


Figure P.173 Pulmonary system.

Pulsar

[astrophysics/astronomy, general] Collapsing spinning STAR, “end of life,” resulting in increased density with decreasing angular momentum and associated increasing ANGULAR VELOCITY (ω) (resembling a figure skater performing a pirouette, pulling in the arms and legs). The rotational ENERGY of the pulsar follows from Newtonian physics as $E_{\text{rot}} \sim (1/2)MR^2\omega^2$, with R the radius of the pulsar and M its mass. One known pulsar in the CRAB NEBULA has a mass equivalent to our SUN, however only at a 25 km diameter due to the collapse. The Crab Nebula pulsar (“Crab pulsar”) rotates at $\omega = 60\pi \text{ rad/s}$, emitting X-RAY and gamma radiation at pulsating intervals. The pulsar emission is generally erratic and irregular in both frequency and MAGNITUDE, as well as spectral profile, but will generally resemble the angular period (see [Figure P.174](#)).



Figure P.174 Supernova remnant and pulsar wind nebula in the constellation of Taurus.

Pulsatile flow

[biomedical, fluid dynamics] Many systems have a periodic flow pattern based on the mechanism of action of the device providing the ENERGY for the flow. In biological applications, the pulsatile flow is provided by the beating HEART. The flow process in biological systems is very complex due to the COMPLIANCE of the system (vascular dilation/stretch), and downstream RESISTANCE that can be influenced by mechanical and hormonal functions (e.g., muscle contraction and adrenaline). Other mechanical pulsatile systems are piston pumps, rotary pumps, and for instance windmills with a paddle system operating with ANGULAR VELOCITY ($\omega = v2\pi$, where v represent the alternation frequency). The flow in mechanical systems can be analyzed using the (time-dependent) Navier–Stokes equation ($\rho(\partial u/\partial t) = -(\partial P/\partial z) + \mu\{(\partial^2 u/\partial t^2) + [(1/r)(\partial u/\partial r)]\}$, with the boundary condition ($\partial u/\partial z = 0$) assuming that the FLUID is incompressible (constant density ρ); the tubes are rigid with constant radius r , for LAMINAR FLOW at flow velocity u , driven by an applied PRESSURE (P) gradient as a function of the axial direction z . Developing the pressure gradient in a series will prove to be beneficial: $(\partial P/\partial z) = \sum_{n=1}^N C_n e^{in\omega t}$, disregarding the steady-state background flow that can be incorporated in various ways (e.g., $n = 0$) and the velocity is directly in line with the pressure fluctuations (*also see BLOOD FLOW*) (see [Figure P.175](#)).



Figure P.175 Pulsatile flow used during a tooth-cleaning procedure.

Pulse oximeter

[biomedical, optical] Optical sensor device used to determine the partial oxygen SATURATION of BLOOD circulating in a biological system. The pulse oximeter relies on two aspects: PULSATILE FLOW and differential absorption between oxyhemoglobin (HbO_2) and deoxyhemoglobin (hemoglobin Hb). Hemoglobin has a much higher absorption in RED, at approximately 660 nm, while oxygenated hemoglobin has a slightly higher attenuation in the INFRARED (IR) 940–960 nm bandwidth. The pulsating nature brings fresh oxygenated blood in the tissue region on a period interval matching the heartbeat. Comparing the attenuation at two or more wavelengths as a function of time allows the oxygenated portion to be segregated out and yields the expression for the percentile oxygen saturation (SpO_2) as
$$\text{SpO}_2 = \left\{ \mu_{a\lambda=\text{red}}(\text{Hb}) / [\mu_{a\lambda=\text{red}}(\text{Hb}) - \mu_{a\lambda=\text{red}}(\text{HbO}_2)] \right\} - \left\{ \mu_{a\lambda=\text{IR}} / [\mu_{a\lambda=\text{red}}(\text{Hb}) - \mu_{a\lambda=\text{red}}(\text{HbO}_2)] \right\}^*$$

$\left[\ln(\psi_{\lambda=\text{red}}) - \ln(\psi'_{\lambda=\text{red}}) \right] / \left[\ln(\psi_{\lambda=\text{IR}}) - \ln(\psi'_{\lambda=\text{IR}}) \right] \}$, where μ_a represent the spectral attenuation coefficient and ψ the radiance of the LIGHT at the respective wavelength (see Figure P.176).

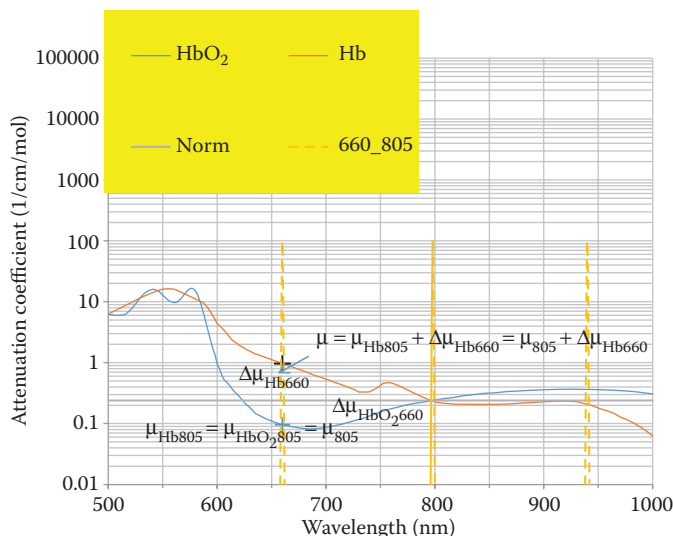


Figure P.176 Optical background in pulse oximetry for the determination of the oxygen saturation of blood.

Pump

[fluid dynamics, thermodynamics] Mechanical device designed to move fluids. The fluids can include PARTICLE solutions (slurry, waste). Many different mechanism apply to the pumping action, ranging from a diaphragm, pistons to screws and also peristaltic action. The peristaltic action is known for the transport of emulsions in the esophagus and intestinal tract for mammals. The lobe pump is generally used for transporting cooling FLUID in automobiles. Old-fashioned plunger-operated hand pumps for water displacement are found to very effective and require no other ENERGY source than MUSCLE action. Another low-energy pump operating on a similar mechanism is the bobbing oil-pump found at OIL wells. A pump that requires no power to operate, except to initially get the process started is the siphon. The siphon requires a negative pressure to fill the tube, and gravitational pull will maintain flow as long as the distal end of the siphon (hose) is lower than the entry point and the entry point remains submerged at all times to prevent AIR from entering into the system, hence defeating the VACUUM. Pumps satisfy the Bernoulli and Navier–Stokes equations (see Figure P.177).



(a)



(b)

Figure P.177 (a) Water pump and (b) oil pump.

Purcell, Edward Mills (1912–1997)

[astrophysics/astronomy, atomic, biomedical, nuclear] Physicist from the United States who won a Nobel Prize for his discovery of the nuclear MAGNETIC RESONANCE effects of certain LIQUID and solid media in 1952. Additional efforts of Purcell were in RADIOASTRONOMY and microwave technology (see [Figure P.178](#)).



Figure P.178 Edward Mills Purcell (1912–1997).

p-wave

[biomedical] In the ELECTROCARDIOGRAM (ECG) of the HEART the DEPOLARIZATION wavefront starts in the atrium that excites the ventricle, where the QRS-complex is representative of the depolarization of the ventricular cardiac MUSCLE. The *p*-wave is the depolarization of the atrium resulting from the SA-node trigger (natural PACEMAKER; sinus node or sino-atrial node [sino-auricular]; located on the right atrium) (see [Figure P.179](#)).

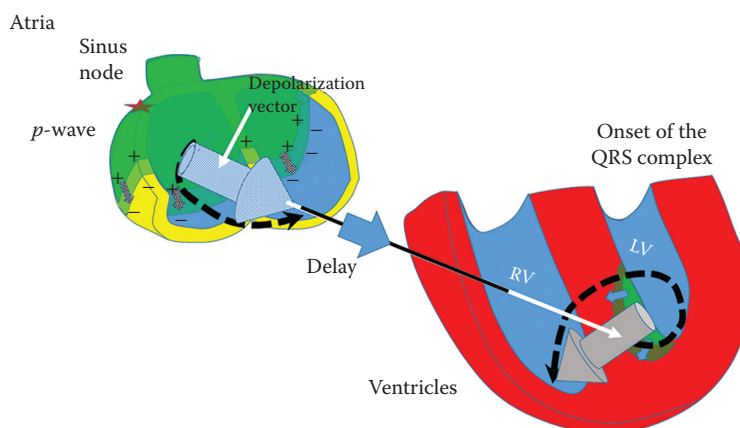


Figure P.179 Atrial *p*-wave and its relevance in the electrocardiogram (ECG). The QRS-complex is the main segment for ventricular electrical cell-membrane depolarization and repolarization activity.

Pyroelectricity

[acoustics, atomic, electromagnetism, fluid dynamics, general, mechanics, quantum, solid-state, thermodynamics] Electrical potential generated by heating certain crystalline structures. The thermal effect results in a LATTICE structure reorganization that produces a permanent ELECTRIC DIPOLE structure that aligns, forming a polarized structure.

Pythagoras (c. 570–c. 495 BC)

[computational, general] Pythagoras of Samos was a scientist and mathematician from Greece. Supposedly, a great deal of his mathematical knowledge was influenced by Babylonian scientists during his captivity in what is now known as the Persian Empire. Apart from the introduction of the PYTHAGOREAN THEOREM, Pythagoras is known for his work on astronomy and discovered the OCTAVE aspect of VIBRATION frequencies for string instruments. Pythagoras and his followers also introduced the principle that the SUN was the center of our planetary system based on certain mathematical principles of PLANETARY MOTION as observed with rudimentary devices. However, this concept was not generally accepted until the late fifteenth century, NICOLAUS COPERNICUS (1473–1543) (see [Figure P.180](#)).

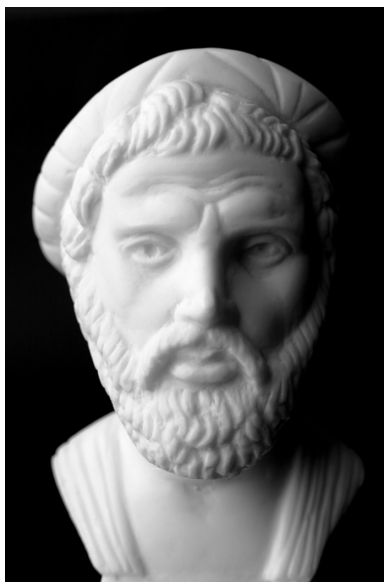


Figure P.180 Artist impression of what Pythagoras (c. 570–c. 495 BC) may have looked like.

Pythagorean theorem

[computational, general] Geometric analysis of a triangle linking the lengths of the three edges with respect to the longest edge (c) as to the remaining edges (respectively a and b): $c = \sqrt{a^2 + b^2}$. The Pythagorean theorem was defined by the Greek mathematician PYTHAGORAS (approx. 570–490 BC).

PZT

[acoustics, biomedical, electromagnetism, general, mechanics] Specifically the material: lead (Pb)-zirconate (Zr)-titanate (Ti) (PZT; $\text{Pb}[\text{Zr}_m\text{Ti}_{1-m}]\text{O}_3$, where $0 \leq m \leq 1$), a synthetic ceramic material used as an acoustic TRANSDUCER. PZT in its indigenous state exhibits no piezoelectric properties of its own. When the PZT material is heated past the Curie point in temperature, the ceramic material can have the

internal dipoles to be aligned by means of an externally applied electric field. The PZT is in this manner used to create ACOUSTIC WAVES resulting from an alternating electric field, usually in the MHz range for ULTRASOUND imaging. The speed of sound in the artificial ceramic PZT material is approximately 4000 m/s. The operating frequency of the medium is determined by the combined conditions of the speed of sound and the thickness of the medium. The half wavelength of the SOUND pulse will need to match the dimension of the ceramic, the thickness; for a 5 MHz (i.e., center frequency) pulse the wavelength is $\lambda = v_{\text{sound}}/\nu = 4000/5 \times 10^6 = 0.8 \text{ mm}$, which yields for the thickness 0.4 mm. The RESONANCE FREQUENCY of the PZT block is achieved from a short block-WAVE voltage spike in the μs range (see PIEZOELECTRIC TRANSDUCER).



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Q Equation

[atomic, chemical, nuclear] Reaction quotient, describing the transposition of states and ENERGY configurations. The reaction quotient for a chemical process is defined as the ratio of the concentration of products to the concentration of reactants, for instance in a reaction with ingredients $A; B; C; D$ at relative quantities $a; b; c; d$ in reaction $aA + bB \rightleftharpoons cC + dD$, with respective (molar-) concentrations $[A]; [B]; [C]; [D]$, proceeding as $a[A] + b[B] \rightleftharpoons c[C] + d[D]$, which yields the reaction quotient $Q_c = C^c D^d / A^a B^b$. This can provide the change in Gibbs free energy (ΔG) as ($\Delta G = \Delta G^0 + RT \ln Q_c$), at temperature T with $R = 8.3144621(75) \text{ J/kmol}$ the GAS constant, applied to SOLUTION (see Figure Q.1).

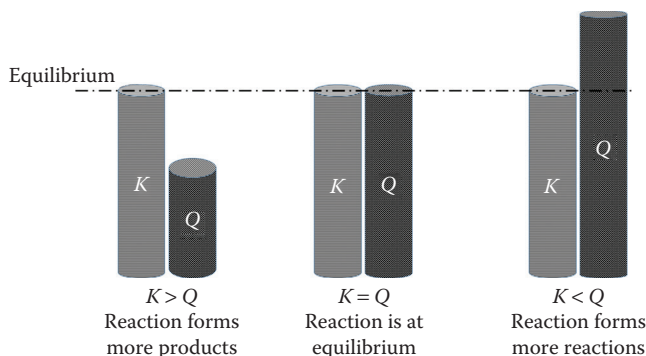


Figure Q.1 Diagram representing the implication of the Q equation. Reaction example: $\text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}_2(g) + \text{H}_2(g)$ (g: gas) in molar quantities: $\text{CO} = 1.00 \text{ mol}$, $\text{H}_2\text{O} = 1.00 \text{ mol}$; $\text{CO}_2 = 2.00 \text{ mol}$, $\text{H}_2 = 2.00 \text{ mol}$, with $Q_c = [\text{CO}_2][\text{H}_2] / [\text{CO}][\text{H}_2\text{O}] = 2 \times 2 / 1 \times 1 = 4$, while the (gas-) equilibrium constant is defined in relative quantities as follows: 1 unit CO reacts with 1 unit H_2O yielding 1 unit CO_2 and 1 unit H_2 with equilibrium constant $K = (\text{CO}_2)(\text{H}_2) / (\text{CO})(\text{H}_2\text{O}) = 1 \times 1 / 1 \times 1 = 1$.

Q Factor

[acoustics, biomedical, computational, electronics, mechanics, nuclear] QUALITY FACTOR, dimensionless parameter used as an indicator for the mechanical or electronic dampening of the MAGNITUDE pertaining to an oscillatory phenomenon. The Q factor is an indication of the inflicted AMPLITUDE reduction with respect to the free OSCILLATION. In ULTRASOUND scanning, for instance, low Q is required pertaining to DOPPLER imaging, and does not imply any value judgment of the material used to generate the specific acoustic frequency band. An ultrasound probe (for instance, made from PZT material) will have a dampening efficiency that is expressed as $Q = \nu_0 / \Delta\nu$, where ν_0 is the center frequency of the material or RESONANCE FREQUENCY and $\Delta\nu$ the bandwidth of the mechanism with enclosure and materials in close contact with the walls of the piezoelectric structure, acting as dampeners. A high Q factor is an

indication of a narrow resonance peak. In nuclear reactions the Q VALUE has a different meaning from the Q factor, in that case indicating the net gain in kinetic ENERGY. Alternatively, in MECHANICS it relates to the length of the crank arm for a bicycle paddle. The bicycle paddle DISTANCE between the attachment to the axis through the gear sprocket (chain ring) for the chain and the platform bicycle pedal (*also see* QUALITY FACTOR) (see Figure Q.2).

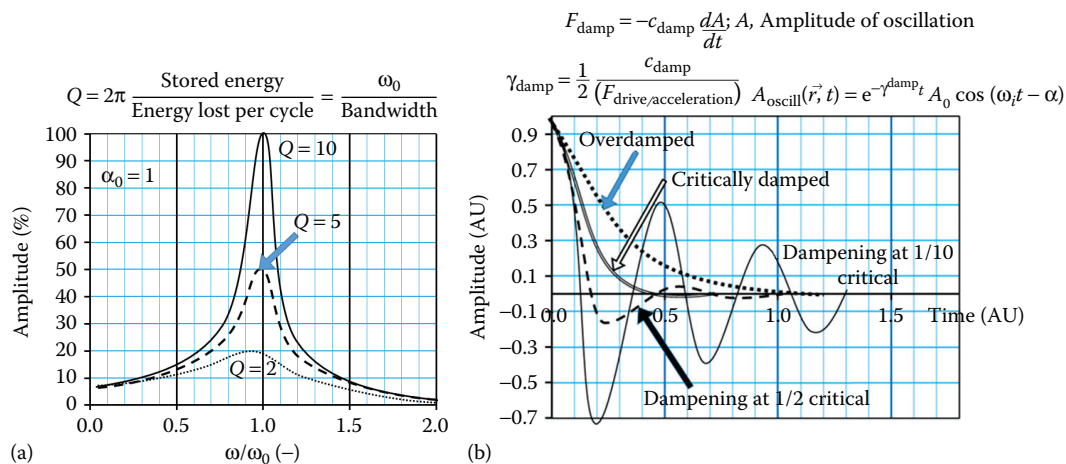


Figure Q.2 (a,b) Damping effect for amplitude of oscillation (either mechanical or electronic) for conditions defining specific Q factors.

Q of reaction

[atomic, nuclear] See Q VALUE.

Q Phase

[thermodynamics] Heterogeneous state, composite system of phases that are in MUTUAL STABLE EQUILIBRIUM. For alloys, the Q -phase designates a condition of specific structure. In the aluminum–copper–magnesium–silicon alloy for instance, the Q phase is the compound $\text{Al}_5\text{Cu}_2\text{Mg}_8\text{Si}_6$. This alloy Q phase is formed during the SOLIDIFICATION process and has inferior mechanical properties. The alloy Q phase can be predicted and subsequently avoided by a computational thermodynamic approach, using isothermal phase diagrams with regard to the PHASE stability (see Figure Q.3).

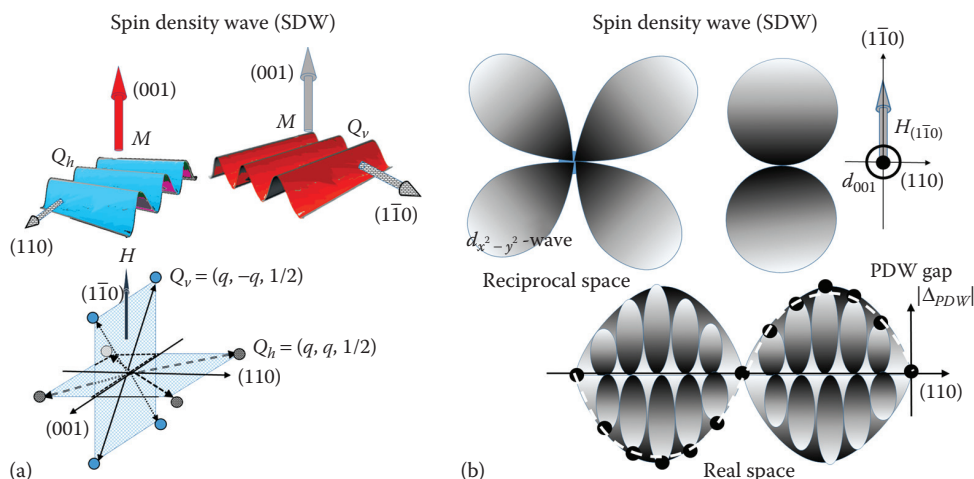


Figure Q.3 (a,b) Electronic matrix with respect to the Q phase of Cooper pair electrons in an alloy structure describing the superconductivity conditions under the influence of an applied external magnetic field, where the magnetic field direction controls the complex quantum state with respect to the Q phase. The Q -phase diagram illustrates the Q vectors associated with the spin-density waves for the alloy CeCoIn_5 (cerium-cobalt-indium), describing the magnetic Bragg positions corresponding to the magnetic field direction in reciprocal space. In this situation, the Q phase illustrates the quantum critical point defining magnetically induced superconductivity.

Q Space

[computational, condensed matter] Q space analysis in computational data analysis provides an alternative to diffusion-weighted imaging (DWI). Q space provides an estimation of maximum likelihood of processes and events, for instance the SCATTERING OF RADIATION by particles or discontinuities. Q space analysis involves plotting the scattered wavefunction (and respective PHASE function) magnitude versus the MAGNITUDE of the scattering WAVE vector: $q = (4\pi/\lambda) \sin(\theta/2)$, using a double log plot. The Q space analysis allows for the estimation of the probability density function (PDF) for molecular DIFFUSION without the need for assumptions with regard to a specific Gaussian shape. One particular application is in the IMAGE analysis for magnetic resonance imaging (MRI). Q space represents wavelength (λ) (long wavelength corresponding to small q) with respect to displacement (location: r). It is a transform from the diffusion TENSOR (see Figure Q.4).

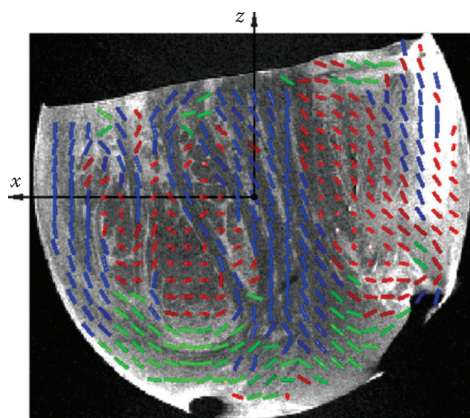


Figure Q.4 Q -space map obtained by magnetic resonance imaging. Quantitative analysis of Q -space (QUAQ) data for a section of a human pons acquired on a 14.1T VARIAN NMR imager with 90 Q vectors (corresponding diffusion gradients with 3 strengths $\times$ 30 directions): estimated distribution of neuronal bundles illustrated by cylinders superimposed over a high-resolution spin-echo image of a transverse section of a human rostral pons. The predominant orientation of the neuronal bundles is indicated in blue for the z -direction, green for the x -direction, and red for the y -direction (out of plane axis). (Courtesy of L. Guy Raguin.)

Q Switching

[optics, quantum] Pulsing mechanism used to form an extremely high radiance laser pulse with an extremely short duration, that is, *Q*-switched laser. *Q*-switched laser pulses are convenient in tattoo removal based on the short thermal interaction, preventing thermal DIFFUSION, which would result in ambient damage. *Q*-switched laser pulses are in the order of nanosecond duration. The pulsation is achieved by influencing the losses in the cavity, diminishing the laser emission process while gaining on INVERSION. The reduction in “emission” of the LASER acronym can be achieved by any of the following means: rotating MIRROR, SATURATION of a programmable absorbing medium, acousto-optic modulation of the path within the cavity, and electro-optic modulation of the path within the laser cavity, for instance, by means of a Pockels CELL. The *Q* switching modulates the rate equation of the LASER action mechanism on an atomic level within Einstein’s population inversion process, with a time constant embedded in the DECAY constant of the cavity, indicative of the depletion of the EXCITED STATES. The loss is virtually instantaneously switched to “low” to release all the stored inverted state ENERGY as a short PHOTON pulse for the duration of the low loss. The pulse duration (τ_i) is a function of the IONIZATION decay rate as $dn(t)/dt = K\{N_i - N_{th}\}n(t) \approx (r_i - 1)/\tau_i$, where $r_i = N_i/N_{th}$ is the initial inversion ratio, with N_i the POPULATION INVERSION directly after switching and N_{th} the threshold inversion immediately after switching, and $n(t)$ is the cavity photon number (~number of excited states). *Q*-switched lasers generally operate in a pulse sequence range of hundreds of hertz to megahertz with below nanosecond pulse duration (e.g., picosecond laser pulse duration used for tattoo removal with minimal peripheral thermal damage, due to the short thermal diffusion time) at output energy levels exceeding J. In 1958, GORDON GOULD (1920–2005) proposed the concept of *Q* switching, but the practical implementation was applied in the state-of-the-art ruby laser of the day by Robert W. Hellwarth (1930–) and Fred J. McClung (1907–2014) in 1961 by means of a Kerr cell shutter, operating based on electrical switching placed within the laser cavity (see Figure Q.5).



Figure Q.5 Beautician applying a *Q*-switch laser for cosmetic skin modification based on photocoagulation processes.

Q Value

[chemical, nuclear, solid-state] In nuclear reactions, the Q value is an indication of the net gain in kinetic ENERGY (KE), standing with respect to the rest energy: $Q = \sum (Mc^2)_{\text{before}} - \sum (Mc^2)_{\text{after}} = \sum \sum KE_{\text{after}} - \sum \sum KE_{\text{before}}$, where $c = 2.99792458 \times 10^8$ m/s is the speed of LIGHT and M the respective masses in the processes. In PARTICLE physics, the Q value represents the DECAY of a particle; for instance, the decay for a NEUTRON is described in relativistic energy as $Q = (m_n - m_p - m_{\bar{\nu}} - m_e)c^2$, with m_n the neutron mass, m_p the proton mass, $m_{\bar{\nu}}$ the mass for the antineutrino, m_e the electron mass, and $c = 299792458$ m/s the speed of light. Not to be confused with the Q FACTOR (see [Figure Q.6](#)).

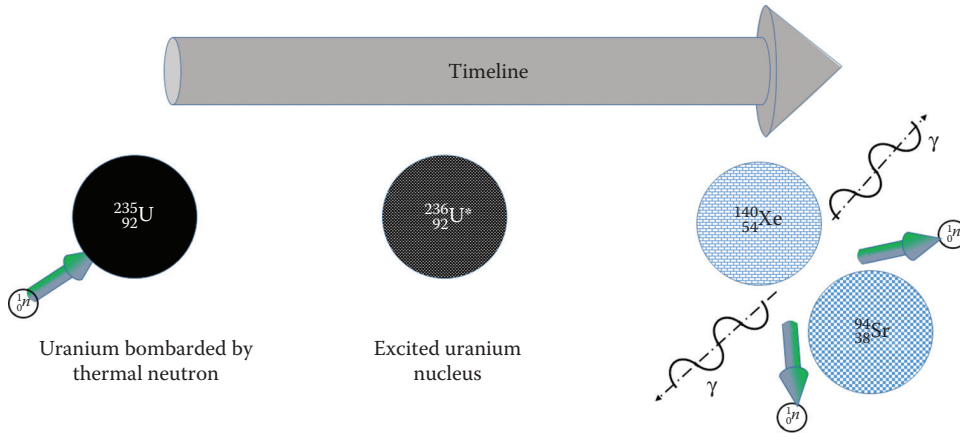


Figure Q.6 Diagram illustrating the mass equivalence with respect to the Q value for a nuclear fission process.

Q-T Interval

[biomedical] Time interval for each heart beat, defining the ventricular DEPOLARIZATION (Q ; in the QRS segment of the EKG) with respect to the subsequent atrial depolarization (T) for the next contraction of the atrium, lowed by the ventricular contraction, perfusing the body with BLOOD (see [Figure Q.7](#)).

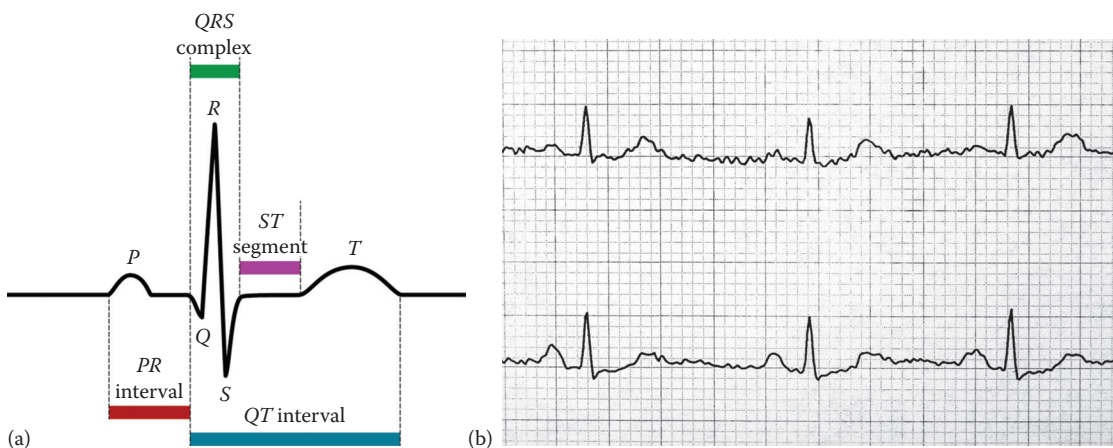


Figure Q.7 (a,b) The relevance of the Q - T interval in the electrocardiogram, indicating the time it takes for the heart to contract and subsequently refill with blood before initiating the next contraction. The Q - T interval is a function of exercise history, the age, and gender of the individual, as well as the regularity and frequency of the standard heart rate. A long Q - T interval represents the deviations in the heart's electrical recharging system from the mean with respect to the overall population, and can be genetically defined or have correlation with a broad range of diseases, not necessarily heart related.

Quadrupole moment

[atomic] Description of the deviation from a spherical charge distribution in the NUCLEUS with respect to the nuclear moment, defined as $Q_e = (1/e) \int r^2 (3 \cos^2 \theta - 1) \rho d\tau$, where θ is the azimuth ANGLE in reference to the projection of the total SPIN of the charge ELEMENT $\rho d\tau$ in the direction where this is maximized for QUANTUM NUMBER $m = I$ (I is the TOTAL ANGULAR MOMENTUM for the spin) at location r , and $e = 1.60217657 \times 10^{-19}$ C is the ELECTRIC CHARGE. The quadrupole moment provides the expectation value for the charge distribution and respective spin angular momentum configuration. Note that the quadrupole moment is nonzero for nuclei that have the total angular momentum greater than or equal to one ($I \geq 1$). The quadrupole momentum can provide details about the internuclear forces. The quadrupole moment is negative for nuclei with a closed (spherical) shell and that possess an additional positive PARTICLE. A nearly closed shell will yield a quadrupole moment that has a positive denomination (prolate nuclear shape). The electric quadrupole moment for a nucleus can also be described in TENSOR format as a function of the wavefunction for the respective nuclear states (Ψ_N), for the corresponding Cartesian components x_i : $Q_e = \sum_{k=1}^Z e (3x_i x_j - \delta_{ij} r^2) |\Psi_N|^2 d\tau$, where δ_{ij} is the KRONECKER DELTA FUNCTION (see Figure Q.8).

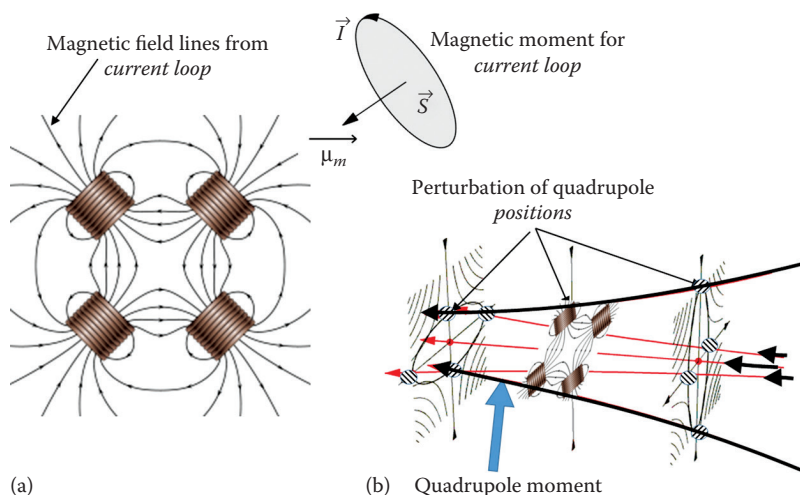


Figure Q.8 (a) Macroscopic quadrupole rods of an analyzer from a triple quadrupole mass spectrometer, and (b) diagram of the associated field distribution under the wavefunction affected changes in nuclear states with a perturbation in magnetic field distribution and associated quadrupole moment. The magnetic moment is a direct function of the magnetic strength of each of the poles and the respective separation between the various poles, constructing a complex vector summation subject to recursive influences from the “other” poles performed in a perturbation analysis.

Quality factor

[nuclear, optics] The quality factor is used in several locations in PHYSICS; ionizing radiation and laser radiation are two specific scientific designations of interest. With respect to ionizing radiation the quality factor is an equivalence indicator for RADIATION in comparison to human risk during exposure of X-RAY radiation. The following quality factor applies to the respective sources of radiation: γ , $Q = 1$; β , $Q = 1$; α , $Q = 20$; NEUTRON, $Q = 10$, proton (high energy), $Q = 10$. In laser design the quality factor dictates the efficiency of a laser cavity: $Q_f = \omega t_{\text{out}} / \delta_c = (4\pi L / \lambda) (1 / \delta_c)$, for a WAVE with wavelength λ of a cavity with time of flight at the output mirror $t_{\text{out}} = 2L / c$ ($c = 2.99792458 \times 10^8$ m/s is the speed of LIGHT and L is the laser cavity length), with δ_c the “loss coefficient” expressing the fractional loss over the

REFLECTION—transmission path. In this case the quality factor determines the line width, $\Delta\omega = 2\pi\Delta\nu$ ($\nu = c/\lambda$ the frequency), of the laser beam (see Figure Q.9).

Type of radiation	Rad	Q Factor	Rem
X-ray	1	1	1
Gamma ray	1	1	1
Beta particles	1	1	1
Thermal neutrons	1	5	5
Fast neutrons	1	10	10
Alpha particles	1	20	20

Figure Q.9 Quality factor with respect to dose equivalence for radiation exposure.

Quanta

[atomic, general, mechanics, optics, photons, quantum] Discrete quantities of ENERGY or charge, or mass. The QUANTUM of charge was named by George Johnstone Stoney (1826–1911) in 1891 as the electron. The quantum for electromagnetic RADIATION is the PHOTON, named in 1926 by Frithiof Wolfers (1890–1971) and Gilbert N. Lewis (1875–1946).

Quantification

[acoustics, computational, image] Mechanism used in ULTRASONIC IMAGING applied to boundary detection. The acoustic quantification provides a regional analysis.

Quantized Dirac equation

[computational, energy, general, thermodynamics] Mathematical description that applies to the interaction of the electric field resulting from the electron current density of a system, with associated ELECTRO-MAGNETIC FIELD configuration (atomic, or generalized QUANTUM—mechanical particles) as well as the photons entering and leaving the system on the electron “self-field” expression. The electron current density for a flow of charges with net charge q : $J^\mu(x) = iq/2 [\Psi(x), \gamma^\mu \Psi(x)]$ ([,] the commutator; γ^μ the set of four 4×4 Dirac matrices defined by $\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$, where $g^{\mu\nu} = \text{diag}(-1, +1, +1, +1)$ is the matrix diagonal and $\{\gamma^\mu, \gamma^\nu\}$ is the anticommutator). The adjoint wavefunction $\bar{\Psi}(x)$ is defined through the Hermitian conjugate: $\gamma^{\mu*} = -\mathbb{A}\gamma^\mu\mathbb{A}^{-1}$, as $\bar{\Psi}(x) = \mathbb{A}\Psi^*(x)$, where $\mathbb{A}$ is the 4×4 Hermitian matrix. This provides the function of the WAVEFUNCTION ($\Psi(x)$) SOLUTION to the SCHRÖDINGER EQUATION as $[\gamma^\mu \partial_\mu + iq\gamma^\mu (\mathcal{A}_\mu(x) + \mathcal{A}_\mu^{\text{ext}}(x)) + m_0] \Psi(x) = 0$, with

$$\partial_\mu = \left(\frac{\partial}{\partial x_0}, \nabla \right)$$

(∇ the Laplace second derivative matrix) the differential operator, $\mathcal{A}_\mu^{\text{ext}}(x)$ the (classical) external electromagnetic field, $\mathcal{A}_\mu(x)$ the field from the entering photons combined with the “virtual photons” of the electron self-field, and m_0 the charge mass associated with q .

Quantum

[nuclear, quantum] A discrete quantity of radiative (electromagnetic) ENERGY equal to the product of its frequency and Planck's constant. The equation is $E = h\nu$ (see [Figure Q.10](#)).



Figure Q.10 Postage stamp dedicated to the quantum concept, specifically pertaining to light, dedicated to Max Planck (1858–1947).

Quantum chromodynamics

[general, high-energy] COLOR identification of GLUON exchange with respect to the interaction between quarks. The color QUANTUM gluon has a spin 1 and is a massless VECTOR BOSON. The vector boson is described by means of a four-dimensional wavefunction. The GLUON offers eight different coupling mechanisms that are represented by color-GAUGE THEORY as eight massless gluons. The color denominations are approximately as follows: green versus antigreen: magenta; RED versus antired: cyan; blue versus antiblue: yellow; and so on, less well defined in some cases.

Quantum concentration

[energy, thermodynamics] The number of particulate constituents per unit volume with a separation DISTANCE that is equal to the DE BROGLIE WAVELENGTH, defined as $n_Q = \left(\frac{mk_b T}{2\pi\hbar^2} \right)^{3/2}$, with $\hbar$ the Planck constant h divided by 2π , $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann coefficient, and m the mass of the elementary unit forming the system or GAS.

Quantum dot (QD)

[biomedical, quantum, solid-state] Macromolecular crystalline structure that has QUANTUM mechanical properties. The quantum dot concept is frequently associated with nanoparticles. In many cases, the quantum dot has a semiconductor material base. The quantum dot can have photoluminescent properties. QDs are also used for biological and chemical marking and tracking due to the highly configurable nature. The name originates from the discovery by ALEXEI EKIMOV (1945–) in a GLASS matrix, published in 1975, and independently in colloidal solutions by Louis E. Brus (1943–) in 1980. The term “quantum dot” was coined by Mark Reed (1955–) in. Quantum dots have an ability to convert LIGHT into ELECTRICITY and vice versa. They have found applications in a range of scientific device designs, ranging from quantum computers, solar panels, light emitting devices, cellular imaging, to siRNA delivery, next to target tumor detection and therapeutic targeting (see [Figure Q.11](#)).

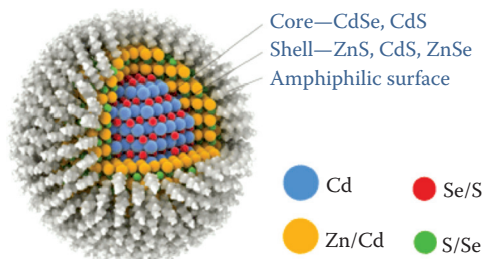


Figure Q.11 Graphical representation of the quantum dot principle. (Courtesy of RusNano, Moscow, Russia.)

Quantum electrodynamics (QED)

[atomic, computational, energy, general, thermodynamics] Relativistic QUANTUM THEORY-based physics principles introduced by Dirac. Electromagnetic phenomena where the electric field is mathematically considered to be ruled by the laws of QUANTUM MECHANICS. One specific quantum phenomenon is the PHOTON. In theoretical physics the merger of the MAXWELL EQUATIONS with SPECIAL RELATIVITY formed the relativistic quantum theory known as QUANTUM ELECTRODYNAMICS (QED). The mathematical treatment of charged particles will range from classic, nonrelativistic to relativistic. QED has its roots in the revelation of the quantum hypothesis for LIGHT (i.e., photons with ENERGY $E = h\nu$) by Max Planck in 1900. Additional fundamental atomic interactions such as ANNIHILATION and PAIR PRODUCTION require a quantized energy format as well as relativistic theory. The first use of QED was by WERNER KARL HEISENBERG (1901–1976) and WOLFGANG ERNST PAULI (1900–1958) when they introduced a spinless relativistic PARTICLE in 1929. Around the same time a relativistic particle with spin $\hbar/2$ was introduced that relies on PAUL ADRIEN MAURICE DIRAC'S (1902–1984) relativistic WAVE EQUATION, where $\hbar = h/2\pi$ is derived from MAX KARL ERNST LUDWIG PLANCK'S (1858–1947) constant h . The ELECTRON SPIN is described perfectly well in the Dirac interpretation of the special relativistic approach to quantum mechanics known as quantum electrodynamics. One notable example of QED is the QUANTIZED DIRAC EQUATION. QED applies to electrons, electromagnetic RADIATION, and ELEMENTARY PARTICLES such as muons, except for hadrons that are governed by strong interaction, which makes the QED theoretical approach more a phenomenological exercise. QED also allowed for the introduction of ANTIMATTER, which helped balance the energy scales in nuclear physics. It forms the basis for the theoretical description in high energy physics.

Quantum field theory

[computational, energy, general, thermodynamics] Interaction of MATTER with each other based on the hypothesis that each object or phenomenon is based on PARTICLE interaction, where each particle has a GRAVITATIONAL FIELD surrounding it that decays with DISTANCE. Generally, all forces between objects are maintained by particle stream, where GRAVITATION is enforced by the hypothetical massless GRAVITON particle. The quantum field theory attempts to portray forces and fields as a physical presence. This concept followed the description of the PHOTON as the “particle” carrying the ENERGY of the electric and MAGNETIC FIELD fluctuations. When enough energy $E = mc^2$ is present in any form, theoretically a real particle can be created to replace the virtual one. Quantum field theory has four assumptions: (1) quantum fields are the essence (there are no other parameters); (2) all quantum fields obey the laws of QUANTUM MECHANICS as well as special relativity; (3) field MAGNITUDE in any location is the likelihood of interacting with a particle at a specific location; and (4) the field QUANTA provide an interaction that is equivalent to the general concept of classical field theory. In quantum field theory, the concept of DEGREES OF FREEDOM is replaced by operators, where one example is the HAMILTONIAN. Another switch is the exchange of POISON BRACKETS in general quantum mechanics by commutators. The way quantum field theory is formulated offers a mechanism to describe and explain the FOUR FORCES of nature: GRAVITY, weak, electromagnetic, and strong.

Quantum fluids

[computational, energy, fluid dynamics, general, thermodynamics] Fluids that have the apparent property of remaining LIQUID at ABSOLUTE ZERO temperature and zero pressure. By definition, a quantum fluid has a ZERO-POINT ENERGY that is comparable with the potential energy associated with the interparticle forces. This property is the definition of fluid, while the THERMAL ENERGY brings it into the quantum field. These fluids have a remarkably large zero-point energy while possessing extremely small interatomic forces. Both factors contribute to the prevention of forming a solid. Examples of quantum fluids are electron “GAS” in sodium, nuclear MATTER in general, NEUTRON matter, and helium: ^3He and ^4He .

Quantum gas

[energy, thermodynamics] Gas or LIQUID solution that has a concentration (n_{gas}) that is greater than or equal to the QUANTUM CONCENTRATION: $n_{\text{gas}} \geq n_Q = \left(mT/2\pi\hbar^2 \right)^{3/2}$. The quantum gas can be either fermions

or bosons, but in contrast with the GAS in the classical regime the FERMI GAS behaves significantly different from the Bose gas.

Quantum jump

[general] The transition of an electron in a high ENERGY (initial energy state: E_i) orbit to a low energy orbit (final energy state: E_f), or ultimately GROUND STATE. The electron orbits are defined in the BOHR ATOMIC MODEL, described by NIELS HENRIK DAVID BOHR (1885–1962). The change in ENERGY LEVEL in the atomic model is associated with a change in the kinetic energy of the ELECTRIC CHARGE; hence, the electron will accelerate. The accelerated charge with an associated electric field will generate a changing MAGNETIC FIELD and hence produce electromagnetic RADIATION, that is, LIGHT, with frequency ν expressed by $h\nu = E_i - E_f$, where $h = 4.1356692 \times 10^{-15}$ Js is the Planck constant.

Quantum level

[general] ENERGY level of an electron or of any atomic system, distinct from any other of its energy levels by discrete quantities dependent on Planck's constant.

Quantum liquid

[astrophysics/astronomy, computational, energy, fluid dynamics, mechanics, quantum, thermodynamics] Concept introduced by LEV LANDAU (1908–1968), specifically for “Bose” type liquids (*also see* BOSE LIQUID).

Quantum magnet

[astro, biomedical, electric, quantum, solid-state] Magnet based on the MEISSNER EFFECT. MAGNETIC FIELD resulting from the transition of a superconductor to the superconducting state.

Quantum mechanics

[computational, electric, energy, general, nuclear, thermodynamics] Theoretical approach to phenomena that are fundamentally discrete in operation; changes occur in increments. Examples of quantized phenomena are angular atomic and subatomic momentum, charge transfer, electromagnetic interactions (e.g., photons), PARTICLE interaction (e.g., COLLISION), virtual particles (QUANTUM ELECTRODYNAMICS), and SPIN (specifically ELECTRON SPIN). One specific phenomenon that falls under quantum mechanics is the description of object MOTION by DE BROGLIE WAVES, specifically for electrons orbiting around a NUCLEUS. One specific application of the de Broglie wave theorem is in ELECTRON MICROSCOPY. The early twentieth century work of Heisenberg on the matrix theory, and the theoretical approach introduced by PAUL ADRIEN MAURICE DIRAC (1902–1984) on the transformation theory and the WAVE MECHANICS from ERWIN RUDOLF JOSEF ALEXANDER SCHRÖDINGER (1887–1961) all converged to the principle of QUANTUM MECHANICS. Under certain conditions, quantum mechanics is also referred to as wave mechanics, specifically in reference to the electron orbit described by de Broglie waves. The de Broglie wave can be considered as prescribing a standing wave for the electron in an orbit, which can be shown to follow the format of the electron packing sequence in orbital layers as described by NIELS HENRIK DAVID BOHR (1885–1962) due to the discrete nature of the boundary conditions for a standing wave. The science of description of atomic

systems in terms of discrete quantum states (*also see* SCHRÖDINGER WAVE EQUATION, WAVE MECHANICS, QUANTUM THEORY, QUANTUM PHYSICS, *and* QUANTUM NUMBER) (see Figure Q.12).

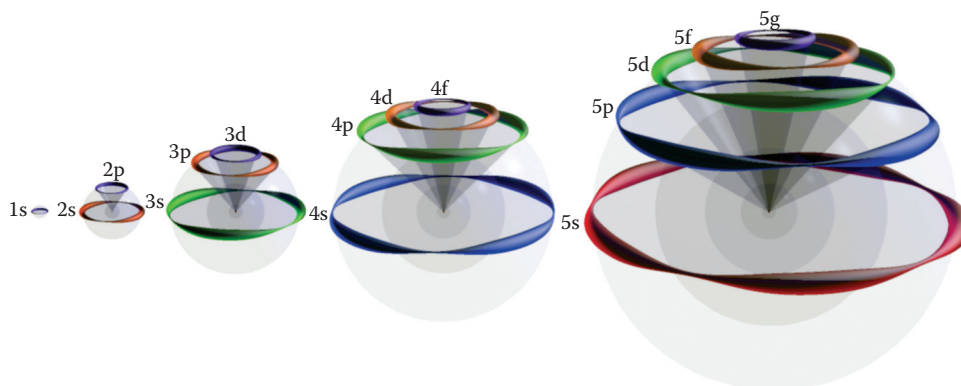


Figure Q.12 Quantum mechanical aspect of electron orbits, in particular the application of the Schrödinger wave function probability distribution for the alleged position of the electron or respectively the physical de Broglie wave aspect to satisfy the boundary conditions for electron orbits presented by PRINCE LOUIS DE BROGLIE (1892–1987) in 1924 as part of his PhD dissertation. (Courtesy of Kenneth Snelson, <http://kennethsnelson.net/>.) Artist representation of the quantum model for electron orbital filling based on the energy levels with reference to the de Broglie wave model from Louis de Broglie. Louis de Broglie proposed that—in equivalence to how ALBERT EINSTEIN (1879–1955) had shown light to have a dual nature—acting both as light waves and particle photons, moving matter may also be represented by a dual character. De Broglie hypothesized that the electron can act as a wave as well as a particle. As an example de Broglie used the electron in Bohr's hydrogen atom. De Broglie provided evidence that his "matter waves" fits perfectly in velocity and wavelength around Bohr's hydrogen atom model's quantized concentric orbits. In the first shell, closest to the nucleus, a single wave could fit resembling a snake biting its own tail. In shell two, there would be two waves; three waves would fit in shell three, and so on. Two years after the publication of the de Broglie dissertation, in 1926, Erwin Schrödinger (1887–1961) adapted the de Broglie's matter wave idea to create the Schrödinger wave equation, which soon became one of the principle tools of quantum physics. In the following year, that is 1927, the Davisson–Germer experiment (CLINTON JOSEPH DAVISSON [1881–1958] and LESTER HALBERT GERMER [1896–1971]) proved that there are indeed electron matter waves, providing evidence for de Broglie waves. The concepts expressed by Louis de Broglie are in this illustration interpreted on an artistic level. In de Broglie model an object comprising the following requirements and, respectively, properties: (1) As with Bohr's quantized electron, a de Broglie orbital wave remains at a single energy shell and can move from one shell to another only by absorbing or transmitting energy, in the form of light (i.e., accelerated charge motion). (2) The electron's negative electric charge is distributed evenly over the orbital circle's circumference. (3) The de Broglie orbit is defined both by orbital magnetism and top-like angular momentum. (4) The orbit incorporates the electron particle's intrinsic spin (as presented by George Uhlenbeck [1900–1988] and Samuel Abraham Goudsmit [1902–1978] in 1925) with the North and South Poles either adding to the orbit's magnetism or, by inverting, subtract from it. (5) De Broglie matter waves are matter-like. In similarity to macro pieces of matter, de Broglie waves occupy exclusive space. Several respective orbits cannot be in the same space at the same time. When the speed of an electron increases, the de Broglie wavelength shrinks by a quantized unit and vice versa. This process may be thought of as resembling striking different notes on a piano, but unlike a glissando for playing a slide-trombone. At each higher shell or orbit the electron slows down and increases its de Broglie wavelength by one notch. This quantization describes the main feature of the atom model described by NIELS BOHR (1885–1962) in 1913 and the associated orbital jumps matching the energy changes indicated in the hydrogen's spectrograph. On initial interpretation the wave for the first orbit is only half the size, unable to surround the equator, the one-wave orbit inherently takes up space on a small meridian of the sphere and hence becomes a 2p electron. Because the electron completes its circle in half the time of the 2s state and because, as illustrated by its transparent cone, the orbit extends outward with respect to the nucleus. At the third shell, de Broglie's original three-wave equatorial orbit complex is represented by the 3s state. When reduced to a two-wave orbit, this will become the 3p state. The final one-wave orbit is identified by the 3d state. The velocity and wavelength for the respective 3s, 3p, and 3d are the same. The smaller the orbit fitting the electron shell, the farther it will project distal to the nucleus. The far-right illustration represents the full range of orbits available to hydrogen atom's electron, from the first shell through the fifth. The s, p, d, f ... electron orbit labels are derived from of the old quantum theory and the ellipsoidal orbit model described by Arnold Sommerfeld (1968–1951) in 1916, which were intended to satisfy the azimuthal quantum number symbolized by (lowercase L). The quantum number describes the electron's angular momentum for orbits at each shell. Sommerfeld's ellipsoidal shapes ranged from true

(Continued)

Figure Q.12 (Continued) circles, to ovals, progressing to straight lines. The de Broglie's matter waves represented a distinctly different interpretation from Bohr's orbiting electron. Alternatively, despite Sommerfeld's ellipsoids extending out from the nucleus, both physicists' atoms were only two-dimensional, that is, flat as a pancake. Irving Langmuir (1841–1957) defined a list of eleven postulates describing the Lewis–Langmuir atom model (see [LANGMUIR](#)). Postulate 1: there is symmetry in the atomic configuration. Postulate 2: the electrons in any given atom are distributed through a series of concentric (nearly) spherical shells, all of equal thickness. Hence, the mean radii of the shells formulate an arithmetic series 1, 2, 3, 4, and the respective effective orbital areas are in the ratios 1: 22; 32; 42. Postulate 3: each shell is divided into cellular spaces, respectively cells, each occupying equal areas in their respective shells and are distributed over the surface of the shells according to the symmetry suggested in Postulate 1. As a result, the first shell contains 2 cells, the second 8, third 18, and the fourth cell holds 32.

Quantum number

[atomic, computational, nuclear, quantum] One of a set of integral or half-integral numbers, one for each degree of freedom, which determines the state of an atomic system in terms of the constants of nature. A QUANTUM MECHANICS approach to determining the ENERGY of electrons in an ELEMENT or ION is based on the results obtained by solving the SCHRÖDINGER WAVE EQUATION for the HYDROGEN ATOM. The various solutions for the different energy states are characterized by the three main quantum numbers: n , ℓ , and m_ℓ . Each orbital has an associated characteristic shape, which reflects the MOTION of the electron pertaining to that particular orbital. This motion is hence characterized by an angular momentum defined by the angular velocity of the electron revolving around the NUCLEUS in its orbit. Electrons in an atom reside in shells characterized by a particular value of n , the PRINCIPAL QUANTUM NUMBER. Within each shell an electron can occupy an orbital that is further characterized by an ORBITAL QUANTUM NUMBER, ℓ , which can take all values in the range $\ell = 0, 1, 2, \dots, (n-1)$; these conditions are traditionally termed “s,” “p,” “d,” “f,” and so on orbitals. Other quantum states are in the description of orbital momentum and orbital spin, where L represents the ORBITAL ANGULAR MOMENTUM of the electron, S represents the SPIN (which cannot change, since that would mean a reversal of rotation direction), J represents the TOTAL ANGULAR MOMENTUM, with M_L the MAGNETIC moment and M_S the spin moment, and in reference $n = 1, 2, 3, 4, \dots$ is the primary quantum number, $\ell = 0, 1, 2, \dots, (n-1)$ the orbital quantum number, and $m_\ell = \ell, \ell-1, \dots, 0, \dots, -\ell+1, -\ell$ the MAGNETIC QUANTUM NUMBER. Similar to an electron moving in its orbital revolution around a nucleus, the electron spinning about its axis has associated with its rotation a well-defined angular momentum. The quantum number m_ℓ is a subset of the quantum number ℓ , where there are $(2\ell+1)$ values associated with each m_ℓ for each value of ℓ , representing the configuration for the s-orbital ($\ell = 0$), three p-orbitals ($\ell = 1$), five d-orbitals ($\ell = 2$), and so on. Furthermore, $m_s = -(1/2), +(1/2)$ represents the spin quantum number for the electrons that identifies the orientation of the spin of one electron relative to those of other electrons in the system. The spin quantum number is associated with the fact that a single electron in free space has a fundamental property, called spin. The spin of the electron represents an inhomogeneous asymmetrical charge distribution spinning around its own axis. Each electron in its orbital configuration (e.g., Bohr model, Rutherford model) is characterized by four base quantum numbers (see [Figure Q.13](#)).

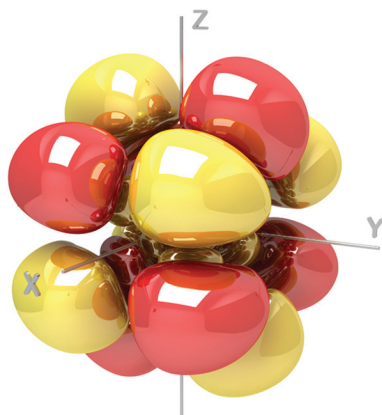


Figure Q.13 Graphical representation of the atomic orbital configuration based on quantum number preferences.

QUANTUM NUMBERS		
SYMBOL	DESCRIPTION	RANGE OF VALUES
n	Principal quantum number: describes the “proximity” to the nucleus, i.e., the range of orbital motion and associated energy levels	1, 2, 3, etc.
ℓ	Azimuthal/orbital quantum number: largely determines the shape of subshell 0 for the s orbital, 1 for the p orbital, etc.	$(0 \leq \ell \leq n-1)$; for instance under the condition $n = 3$; $\ell = 0, 1, 2$ with associated “levels” (s, p, d)
m_ℓ	Magnetic quantum number: defines the orientation of a subshell’s shape. Examples are p_x , p_y , and p_z	$-\ell \leq m_\ell \leq \ell$, for instance under the condition $\ell = 2$, $m_\ell = -2, -1, 0, 1, 2$
m_s	Spin quantum number	Only two possible values for a single electron: $+1/2$ or $-1/2$

Quantum of action (h)

[general] The oscillatory “wavefunctions” in NIELS HENRIK DAVID BOHR’s (1885–1962) atomic model (influenced by LOUIS DE BROGLIE [1892–1987]) could only be satisfied if the WAVE would fit a “circumference,” and hence the closed wave turned out to have discrete values that had a constant with the units of ENERGY multiplied by time ($J \cdot s$), which was the equivalent of momentum multiplied by the traversed DISTANCE, a parameter known as “action” in classical MECHANICS. The constant was derived by MAX PLANCK (1858–1947) as PLANCK’S CONSTANT: $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, which he referred to as the “quantum of action,” due to the discrete nature of the phenomenon. The orbital momentum in classical terms had the following condition for an electron orbit with mass m_e at radii r_n , traveling with discrete velocity v_n : $m_e r_n v_n = n(h/2\pi)$, with n the ordinal for the discrete ORBITS.

Quantum optics

[computational, energy, optics] QUANTUM THEORY pertaining to the bandwidth of optical wavelengths (i.e., visible LIGHT). The processes of detection of light, and propagation as well as generation are all subject to the QUANTUM effects; one specific example is in the coherence of laser light. The topic of “squeezed states” has special significance for the quantum optical approach.

Quantum orbital angular momentum

[atomic] The orbital angular momentum is subject to classical theory based on the fact that there are no external forces; hence, no torque acting and conservation rules apply. The ORBITAL ANGULAR MOMENTUM (L) is quantified as spherical harmonic functions as a SOLUTION to the SCHRÖDINGER WAVE EQUATION with discrete values for the MAGNITUDE expressed as a function of the angular quantum number (ℓ): $L = \hbar \sqrt{\ell(\ell+1)}$, where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ the Planck constant. Similarly, the z -component of the angular momentum has eigenvalues: $L_z = m_\ell \hbar$, with m_ℓ the discrete MAGNETIC QUANTUM NUMBER (also see QUANTUM NUMBER).

Quantum physics, electron shells

[atomic, general, mechanics, nuclear, quantum] The field of PHYSICS that specializes in the theoretical description of events and phenomena that are discrete in nature, specifically pertaining to atomic and nuclear procedures and processes. Quantum physics made its introduction in the 1920s. Quantum physics encompasses, but not limited to, de Broglie waves (introduced by LOUIS DE BROGLIE [1892–1987]), QUANTUM ELECTRODYNAMICS (as introduced by PAUL DIRAC [1902–1984]), the PAULI EXCLUSION PRINCIPLE (as introduced by WOLFGANG PAULI [1900–1958]), relativistic QUANTUM THEORY, the HEISENBERG UNCERTAINTY PRINCIPLE (introduced by KARL HEISENBERG [1901–1976] in 1927), Schrödinger’s work (ERWIN SCHRÖDINGER [1887–1961]),

and the description of **ANTIMATTER** (first experimental indication, the “antielectron,” the positron, by **CARL ANDERSON** [1905–1991] in 1932 (with postulation records dating back to 1928), followed by the antiproton in 1955 and the **ANTINEUTRON** in 1956). The **ZEEMAN EFFECT** is another aspect of quantum physics as well (*also see* **QUANTUM NUMBER**, **QUANTUM MECHANICS**, and **QUANTUM THEORY**).

Quantum randomness

[general] The fact that under probability theory **IDENTICAL PARTICLES**, or **ENERGY** packages (e.g., photons), subjected to identical circumstances (i.e., identical boundary conditions) do not necessarily act in an identical manner.

Quantum spin angular momentum

[atomic] **ELECTRON SPIN** angular momentum belonging to the Dirac relativistic **WAVE** mechanical phenomenon (**PAUL DIRAC** [1902–1984]) as a component of the atomic angular momentum, defined by the **SPIN** quantum number s , as $L_s = \sqrt{s(s+1)}\hbar$, where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ the Planck constant. The z -component of the electron spin is linked with the **MAGNETIC** moment by Dirac as having an intrinsic spin with a $g_s = 2$, value that is twice as large as for the corresponding **ORBITAL ANGULAR MOMENTUM**: $L_{s,\chi} = m_s \hbar$, with $m_s = \pm(1/2)$ the magnetic spin quantum number. The g -factor introduces a correction for the relationship between the magnetic momentum and the angular momentum, based on the difference in charge density with respect to mass density (note that for the orbital **MOTION** the charge density matches the mass density and yields alternatively $g_s = 1$ with respect to the orbital angular momentum). The spin vector will precess with a Larmor frequency, different from the orbital angular momentum vector **PRECESSION** frequency.

Quantum state

[atomic, general, nuclear] Term defining the way in which an atomic system exists at any specific time. This state is often described by means of a complex mathematical function. *see* **QUANTUM LEVEL** (see [Figure Q.14](#)).

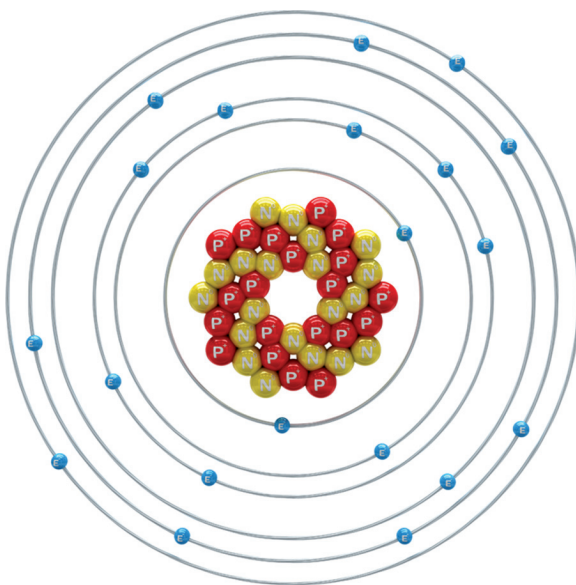


Figure Q.14 Atomic quantum states for calcium: the diagram illustrates one particular orientation only for a specific quantum number configuration.

Quantum theory

[atomic, general, nuclear, relativistic] The concept that ENERGY is radiated intermittently in discrete units of definite MAGNITUDE called QUANTA, under conditions that may be subject to a relativistic approach. The basic principles of quantum theory date back to BLACK BODY radiation concepts from 1859 by the German scientist GUSTAV ROBERT KIRCHHOFF (1824–1887). This was followed by the hypothesis published in 1900 by MAX PLANCK (1858–1947) that energy can only be emitted or absorbed in discrete quantities. On the basis of the experiential observations in 1911 by ERNEST RUTHERFORD (1871–1937) leading to the nuclear model of the ATOM, NIELS HENRIK DAVID BOHR (1885–1962) developed the atom model in 1913, providing additional building blocks that illustrated that classical MECHANICS does not apply on an atomic level. The theoretical transition was fully made by the contributions of ERWIN SCHRÖDINGER (1887–1961) in 1925, partially based on the work of LOUIS DE BROGLIE (1892–1987) published in 1924. Additional components forming the complete story resulted from the HEISENBERG UNCERTAINTY PRINCIPLE introduced in 1927 by WERNER WEISENBERG (1901–1976). Over the years many refinements and additions followed, but the foundation evolved over a time span stretching out over more than 60 years. Also see QUANTUM MECHANICS (*also see* QUANTUM PHYSICS *and* QUANTUM NUMBER).

Quantum total angular momentum

[atomic, quantum] The superposition of the orbital angular quantum effect and the SPIN quantum effect. Under conditions there may be coupling of the spin and ORBITAL ANGULAR MOMENTUM, specifically under the influence of a weak external MAGNETIC FIELD (*also see* L–S COUPLING, QUANTUM NUMBER, TOTAL ANGULAR MOMENTUM, *and* ZEEMAN EFFECT).

Quantum tunneling

[computational, quantum] QUANTUM mechanical phenomenon where a PARTICLE migrates through an ENERGY BARRIER described as a tunnel that under classical PHYSICS would not be attainable. The *quantum tunneling* process was observed by ANTOINE HENRI BECQUEREL (1852–1908) in 1896 and later theoretically defined by GEORGIY ANTONOVICH (GEORGE) GAMOW (1904–1968) around 1928. The “transmission coefficient (T_Q)” for the PROBABILITY of a particle (mass m) with energy E_{particle} traveling through a POTENTIAL BARRIER with height $V_{\text{barrier}}(x)$, which is a function of DISTANCE (r) to the core of the MOLECULE/ATOM, is given as

$$T_Q = \exp\left(-2 \int_{r_1}^{r_2} \sqrt{\left\{(2m/\hbar^2)[V(r) - E]\right\}}\right) / \left\{1 + (1/4)\exp\left(-2 \int_{r_1}^{r_2} \sqrt{\left\{(2m/\hbar^2)[V(r) - E]\right\}}\right)\right\}^2,$$

where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ Planck's constant. Also found described as *tunneling*. (see Figure Q.15).

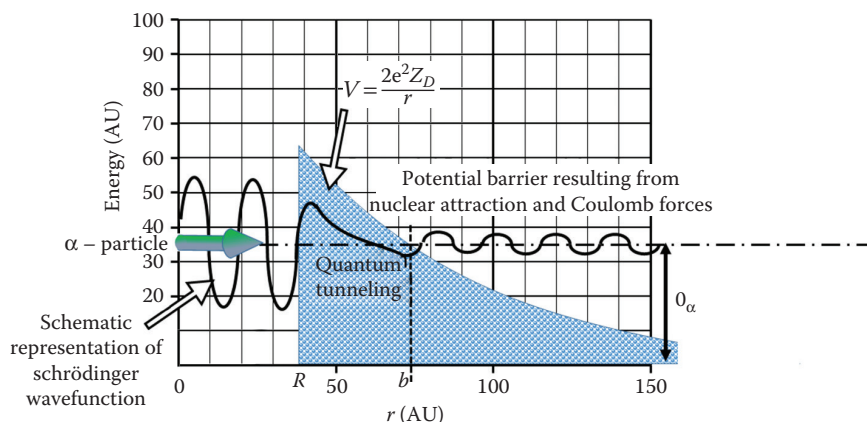


Figure Q.15 Quantum tunneling with respect to the energy configuration of the nucleus of an atom, respectively an atomic model.

Quark

[atomic, general, high-energy] Elementary PARTICLE with the following energetic and momentum designations: first generation: “up” and “down;” second generation: “CHARM” or “strange;” and third generation: “top” and “bottom or beauty.” The subgroup of three varieties of quarks, up, down, and strange, have a fractional charge of $(1/3)e$ and $(2/3)e$, where e represents the standard electron charge. Quarks have standard half spin: $s = 1/2$. They are the latest in FUNDAMENTAL PARTICLES that are known and verified based on the state-of-the-art technology of MEASUREMENT as well as what can be mathematically validated. All “higher order” particles, such as neutron and proton, are constructed of quarks, referred to as hadrons. Electrons (LEPTON) are seemingly stand-alone particles, based on the knowledge at the time of this description. Nonetheless, there are indications that electrons themselves also exhibit quark equivalent “flavors.” Quarks are never found as isolated particles; they are always part of the collective of quarks in the HADRON. A PROTON is composed of two “up” quarks and a “down” quark; a NEUTRON is constructed from the GLUON “strong-force” COHESION between one “up” quark and two “down” quarks. Another particle is, for instance, the PION, constructed from an “up” with an “anti-down” quark, or a “down” quark, combined with an “antiup” quark. In turn, electrons, neutrons, and protons form atoms that constitute the building blocks for MATTER as we know it and work with on a daily basis. The quark concept was introduced in 1964 by both MURRAY GELL-MANN (1929–) and GEORGE ZWEIG (1937–), as independent hypotheses and experimentally verified starting in 1968 by experimental observations at the Stanford Linear Accelerator Center (now known as SLAC National Accelerator Laboratory). The “top” quark was verified as the last in a sequence as recent as 1995 (see Figure Q.16).

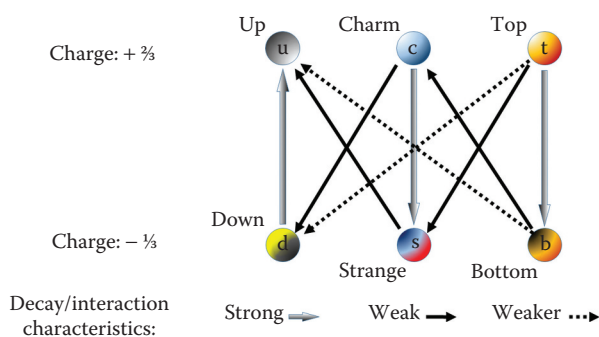


Figure Q.16 The concept of quark illustrated in nonrelativistic terms.

Quark and Antiquark Characteristics									
Flavor	Symbol	Charge	Spin	Baryon Number	Charm	Strangeness	Bottomness	Mass Range (MeV/c ²)	Generation
Quarks									
Up	u	$+\frac{2}{3}e$	$\frac{1}{2}h$	$\frac{1}{3}$	0	0	0	$1.7 \leftrightarrow 3.1$	1st
Down	d	$-\frac{1}{3}e$	$\frac{1}{2}h$	$\frac{1}{3}$	0	0	0	$4.1 \leftrightarrow 5.7$	1st
Bottom	b	$-\frac{1}{3}e$	$\frac{1}{2}h$	$\frac{1}{3}$	0	0	+1	172900 ± 600	3rd
Top	t	$+\frac{2}{3}e$	$\frac{1}{2}h$	$\frac{1}{3}$	0	0	0	$4190 + 180/-60$	3rd
Strange	s	$-\frac{1}{3}e$	$\frac{1}{2}h$		0	-1	0	$100 + 30/-20$	2nd
Charmed	c	$+\frac{2}{3}e$	$\frac{1}{2}h$	$\frac{1}{3}$	+1	0	0	$1290 + 50/-110$	2nd
Antiquarks									
Antiup	$\bar{u}$	$-\frac{2}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	0	0	0	$1.7 \leftrightarrow 3.1$	1st
Antidown	$\bar{d}$	$+\frac{1}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	0	0	0	$4.1 \leftrightarrow 5.7$	1st
Antibottom	$\bar{b}$	$+\frac{1}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	0	0	-1	172900 ± 600	3rd
Anitop	$\bar{t}$	$-\frac{2}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	0	0	0	$4190 + 180/-60$	3rd
Antistrange	$\bar{s}$	$+\frac{1}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	0	+1	0	$100 + 30/-20$	2nd
Anti-charmed	$\bar{c}$	$-\frac{2}{3}e$	$\frac{1}{2}h$	$-\frac{1}{3}$	-1	0	0	$1290 + 50/-110$	2nd

Quark, color of

[energy, general, quantum, relativistic] *See* **COLORS OF QUARKS** *and* **QUARK**.

Quark, flavor of

[energy, general, quantum, relativistic] *See* **FLAVORS OF QUARKS** *and* **QUARK**.

Quartz

[biomedical, optics, solid-state] Optically transparent crystalline lattice structure. Quartz materials are optically active, resulting in a rotation of the **POLARIZATION** direction of transmitted **LIGHT**. Quartz has its special features derived from the polarized electronic state of the **LATTICE** structure. The **OPTICAL ACTIVITY** of quartz is attributed to the helical molecular structure of the quartz crystal. Quartz can be electrically excited to oscillate, acting as a **RADIO WAVE** emission source or tuning receptor for oscillating electric and electronic signals. Quartz can also be made to expand and contract under electrical excitation, forming an **ULTRASOUND** emission source. The chemical base for quartz is silicon and oxygen (SiO_2) (see [Figure Q.17](#)).



Figure Q.17 Raw white quartz; other color quartz crystals are also found. The color of the quartz is the result of “pollution” or doping by other elements, some of which are considered semiprecious gemstones (e.g., amethyst). Most common inclusions are metals as well as phosphorous compounds. Quartz is the second most abundant mineral found on the Earth’s surface. The pure quartz crystal is constructed from SiO_4 (silicon and oxygen).

Quasar

[astrophysics/astronomy] Acronym for “quasi-stellar radio source.” Star-like objects in the **UNIVERSE** that are outside the **MILKY WAY**. Quasars emit a broad range of electromagnetic **RADIATION**, with the most abundant amount of frequencies in the “radio” band of the spectrum. Quasars are presumably galactic cores (assemblies of many stellar sources), hypothetically incorporating “black holes.” The **RADIO** emissions are supposedly a secondary effect resulting from high-energy photons interacting with material outside the

quasar space, originally resulting from excessive high-temperature-based interaction for instance with the BLACK HOLE. The spectral lines of quasars form part of the verification process supporting the “BIG BANG THEORY,” based on the DOPPLER redshift, indicating the general EXPANSION of the universe (*also see* HUBBLE EFFECT) (see [Figure Q.18](#)).

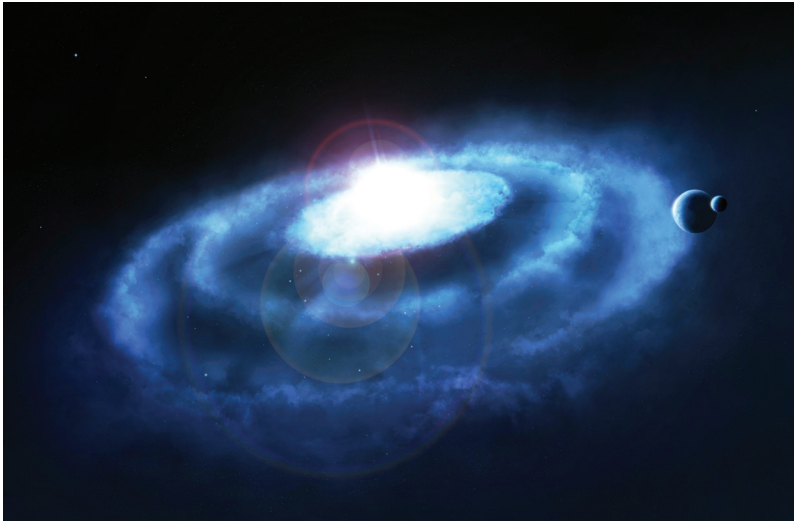


Figure Q.18 Artist impression of the format describing the mechanism of operation for a quasar.

Quasicrystalline solid

[general, solid-state] Molecular or atomic configuration in a regular orderly three-dimensional pattern that is different from crystalline or amorphous (noncrystalline), while being nonrepetitive (not a regular LATTICE) forming a solid that is quasicrystalline.

Quasimonochromatic light

[general, optics] Whereas the term MONOCHROMATIC LIGHT indicates an extremely narrow linewidth of less than 0.5 nm, quasimonochromatic would be the accurate term for this, since the true meaning of monochromatic will described deep into the decimal aspect of the source definition, technically indicating an infinitely duration source. The shorter duration would indicate a lower number of harmonics, an extremely short pulse such as for a Q-switched laser renders a broad linewidth, approaching several nanometers.

Quasiparticle

[atomic, high-energy, optics] Many-body system that possesses excitation levels resembling those of free ELEMENTARY PARTICLES, but may have a convoluted interparticle interaction. One specific example is the Fermi liquid in the LANDAU THEORY, where the electrons of a medium at extremely low temperature (e.g., Helium) can essentially behave as free fermions, although bound (i.e., quasiparticle); this also forms one of the basics of SUPERCONDUCTIVITY and superfluidity. The main complication lies in the distribution function for the “PARTICLE” momentum with respect to the Fermi momentum, which for the ideal particle is a delta function; however, this may not hold true throughout all theoretical processes. In general, the FERMION forms the base for the quasiparticle; however, under special boundary conditions, bosons (term coined by PAUL DIRAC [1902–1984]; e.g., phonon, PLASMON, COOPER PAIR, SPIN WAVE, etc.) may also be considered quasiparticles.

Quasi-steady state

[astrophysics/astronomy, fluid dynamics, geophysics, mechanics, meteorology, thermodynamics] Intermediate states of a system that progress linearly in response to temperature, pressure, and volume changes. The EQUATION OF STATE for the system is well defined, specifically conforms to the IDEAL GAS LAW over discrete steps in time, and changes gradually between incremental episodes. Also known as the quasistatic process. When applied to the UNIVERSE, the Hubble constant would yield a fixed number under quasi-steady-state approximation; however, under longer period examination it will not, since then the process becomes transient. The quasi-steady-state approach is a linearization process with very specific boundary conditions, pertinent to the system under consideration. The considerations for when to label a process quasi-steady state rely on the characteristic time frame for the phenomena within the system; in particular, the processes with the shortest time frame are critical in the analysis. Additionally, the required accuracy of the analysis forms a major scaling factor in the assumption what may be considered quasi-steady state. In first order approximation, one may find that the accuracy is proportional to the relevant time scale (observation time divided by the time frame of the shortest event), and exhibits an exponential behavior. In first-order analysis, when observations are stationary within a time frame that is minimally five (5) times the shortest process of all the processes that define the system, then they can be considered quasi-steady state, with less than 0.7% error in the outcome. However, it will be incorrect to assume that all processes are independent from each other; hence, the exact error will be a convoluted calculation procedure, integrating all factors and interactions. Alternatively, when the consequences of a process are at least ten (10) times the duration of the initiating phenomenon (first-order), then those events can be considered quasi-steady state as well, and since this forms a recursive relation, the dependency may be more quadratic than exponential. These conditions may require one to be more strict due to the fact that they change the boundary conditions, as well as the process itself. One example is that heat DIFFUSION for a femtosecond (*Q*-switched) laser pulse is negligible within the time frame of interest, and hence the process and fallout

for ultrashort laser delivery is frequently quasi-steady state. NUMERICAL solutions to time-dependent equations are always performed under quasi-steady-state conditions, where the boundary conditions need to be adjusted at specified intervals, or dynamically, to account for changes resulting from external influences or due to the processes themselves (see [Figure Q.19](#)).

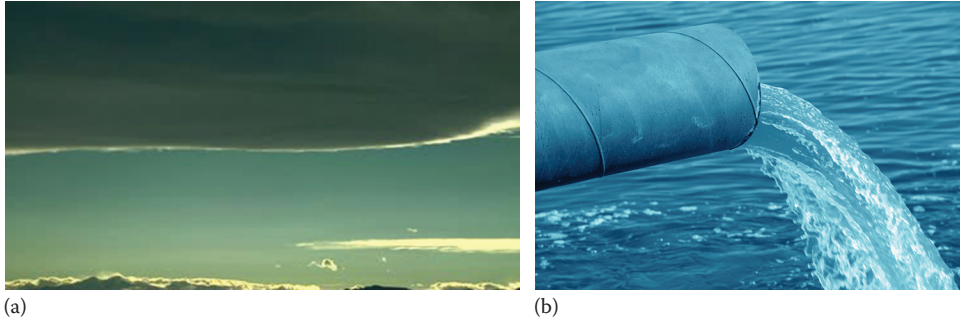


Figure Q.19 (a) Quasi-steady state for meteorological events: the big block of clouds remains steady while a remote steady flow of mountain air provides a backdrop of an active event. The event is still very stable and will not interfere with the contiguous cloud formation in the foreground that is apparently at a distance that remains unaffected by the boundary conditions from the flow pattern. The cloud concentration may move under the influence of atmospheric pressure and bring the clouds close enough to the mountain wave to disturb the equilibrium. (b) Drainage pipe flow that is considered steady state within a broad time frame; however, the flow rate and flow pattern are for instance influenced by the position of the Moon next to the water level in the back country, which in turn will be a function of precipitation and runoff from regional population concentrations and industrial complexes.



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Raab, Oscar (1876–1986)

[biomedical, optics] Medical student from Germany who described the principle of **PHOTOTOXICITY** as the light-mediated enhanced cytotoxicity of eosin on **SKIN** in 1898/1899 and named it photodynamic action. He reported that paramecia cells injected with the dye acridine orange resulted in **CELL** death when exposed to **LIGHT**. The discovery of phototoxicity led to medical applications in cancer treatment and was named photodynamic therapy (PDT). These pioneering efforts in **BIOMEDICAL OPTICS** used the phototoxic effect of the combination of certain dyes with light to treat skin cancer reportedly starting in the period from 1903 through 1907 and this was rapidly followed by the treatment of **EYE** tumors. An illustration of the importance of light in photodynamic therapy applications is specifically in a particularly hard to treat anatomical section: the brain. More easily and more frequently treated oncology conditions are in skin cancer and other superficial tumors, including but not limited to the urinary bladder and intestines (see [Figure R.1](#)).

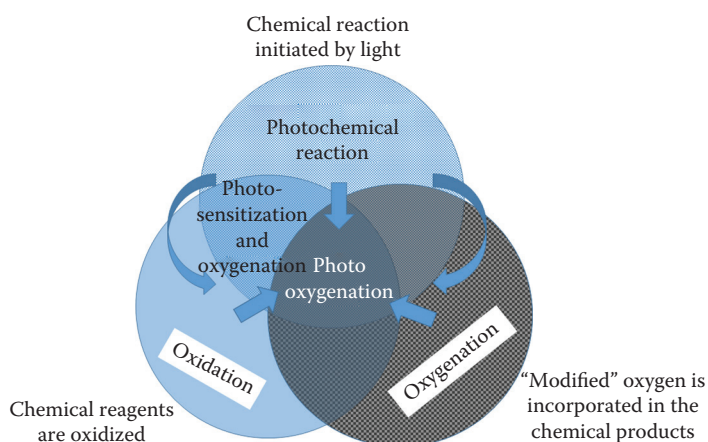


Figure R.1 Diagram of Oscar Raab's (1876–1986) phototoxicity concept. Despite the significant influence on modern medicine, unfortunately no known images exist of Oscar Raab.

Rabi, Isidor Isaac (1898–1988)

[atomic, nuclear] Physicist from Austria (Prussian empire)/(Poland). Rabi is most known for his contributions to the understanding of the **MAGNETIC RESONANCE** and general magnetic properties of the atomic **NUCLEUS** and the evolution of magnetic resonance imaging (MRI), for which he received the Nobel Prize for Physics in 1944. Isidor Rabi's work on the magnetic moments of nuclei involved his prediction and verification that absorbed **ENERGY** from an externally applied electromagnetic **WAVE**, at the appropriate (**RESONANCE**) frequency, would flip the magnetic orientation of the recently discovered protons and neutrons. The **SPIN** would subsequently emit the identical amount of energy when reverting back to the

lower energy orientation. Rabi coined the term “MOLECULAR BEAM magnetic resonance” for this phenomenon. Rabi’s work also led to the development of the atomic clock (see [Figure R.2](#)).

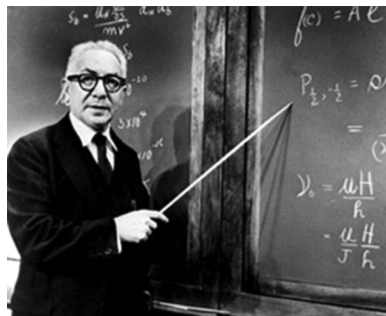


Figure R.2 Isidor Isaac Rabi (1898–1988). (Courtesy of Columbia University Libraries; University Archives, Columbia University in the City of New York.)

Radial quantum number

[nuclear] As applied to a harmonic oscillator applied to Laguerre–Gauss modes. Although not used in general nuclear QUANTUM MECHANICS the radial quantum number (n_r) provides insight in the number of radial nodes of the (radial; in cylindrical coordinates) WAVE function and is tied to the PRINCIPAL QUANTUM NUMBER (n) as $n = n_r + \ell + 1$, where ℓ is the ORBITAL ANGULAR MOMENTUM quantum number, the azimuthal quantum number. In this context the radial quantum number defines the DISTANCE of the electron from the NUCLEUS in the Bohr model. Alternatively, the principal quantum number may also be found referred to as the radial quantum number (see PRINCIPAL QUANTUM NUMBER).

Radial wave equation

[nuclear] See SCHRÖDINGER EQUATION.

Radial wave function

[nuclear] See WAVE FUNCTION.

Radiance ($\Phi(\vec{r}, \vec{s})$)

[biomedical, electromagnetism, general, nuclear, optics] Radiant ENERGY; power emitted, transferred, or received as radiation (W). The radiance has an angular dependence that can be developed in a truncated series of polynomials. In most cases the function that is part of the differential equation can be developed in a series of power series solutions: Legendre polynomials, BESSEL FUNCTIONS, and Laguerre polynomials. Using Cauchy theorem, the expression can be developed in series of orthogonal polynomials: $f(x) = \sum_{k=0}^{\infty} A_k x^k$, as

$$\begin{aligned}\Phi(\vec{r}, \vec{s}) &= \sum_{n=0}^1 \sum_{m=-n}^n Y_n^m(\vec{s}) \Phi_n^m(\vec{r}) \\ &= Y_0^0(\vec{s}) \Phi_0^0(\vec{r}) + Y_1^{-1}(\vec{s}) \Phi_1^{-1}(\vec{r}) + Y_1^0(\vec{s}) \Phi_1^0(\vec{r}) + Y_1^1(\vec{s}) \Phi_1^1(\vec{r}) + Y_2^0(\vec{s}) \Phi_2^0(\vec{r}) + \dots\end{aligned}$$

Also found identified by the parameter $L(\vec{r}, \vec{s})$ (see [Figure R.3](#)).



Figure R.3 The difference in radiance from several floodlights with adjustable focal points.

Radiant energy fluence rate ($E^0(\vec{r}, t)$)

[astrophysics/astronomy, biomedical, energy, thermodynamics] Total radiant power incident on a surface from all directions per unit surface area. The fluence per unit time: $E^0(\vec{r}, t) = dH^0(\vec{r}, t)/dt = d\Psi(\vec{r}, t)/dt$. Also the integrated radiance ($L(r, \theta, \phi, t)$) over full SOLID ANGLE: $E^0(r, t) = \int_{4\pi} L(r, \theta, \phi, t) d\Omega$. Also known as fluence rate. In comparison, the ENERGY per unit area incident on a small sphere is the fluence ($\Psi(\vec{r}, t)$; also found as $H^0(\vec{r}, t)$). For a parallel, none scattered beam incident on a surface the radiant energy fluence rate reduces to “Irradiance,” for example, laser beam on clear semi-infinite medium (no reflective boundaries).

Radiant flux

[general] See RADIATIVE POWER.

Radiation

[atomic, general, optics, quantum] Method of transmission of ENERGY. Specifically, (1) any electromagnetic wave (QUANTUM), (2) any moving electron or nuclear particle, charged or uncharged, emitted by a radioactive substance, (3) acoustic pressure waves, and (4) GRAVITATION WAVE extension of gravitational attraction force through gravitational radiation. The elementary form of radiation is found as electromagnetic radiation, which is the result of an accelerated charge. The ELECTROMAGNETIC THEORY was delineated by JAMES CLERK MAXWELL (1831–1879) in 1861. The concept of electromagnetic radiation resulting from accelerated charges was described by JOSEPH LARMOR (1857–1942) in 1897. In 1903 ERNEST RUTHERFORD (1871–1937) and FREDERICK SODDY (1877–1956) realized that radioactive ELEMENTS (now known as isotopes; introduced by Francis William Ashton [1877–1945] in 1919) spontaneously transform from one chemical substance to another accompanied by the emission of radiation of particulate (e.g., electron [JOSEPH THOMPSON (1856–1940) 1897], PROTON [identified/postulated by WILHELM WIEN (1864–1928) in 1898, named by ERNEST RUTHERFORD in 1920], NEUTRON [discovered by JAMES CHADWICK (1891–1974) in 1932], helium ion: ALPHA PARTICLE) or electromagnetic radiation (e.g., X-RAY, gamma radiation, and visible LIGHT as well as INFRARED radiation). At the time of Rutherford’s and Soddy’s declaration, the ATOM concept was known, however, the NUCLEUS was not discovered as of yet. Natural ACTIVITY resulting in radiation is one mechanism, specific examples are uranium and thorium; artificial radiation is the result of

the application of an external source on a stable ELEMENT, such as the production of X-ray resulting from the impact of fast electrons on metals such as tungsten. Radiation can be classified in ionizing (PARTICLE, high-energy electromagnetic) and nonionizing (mid- to long-wave electromagnetic) (*also see WIEN'S DISPLACEMENT LAW, PLANCK'S RADIATION LAW, and RAYLEIGH-JEAN LAW*) (see [Figure R.4](#)).

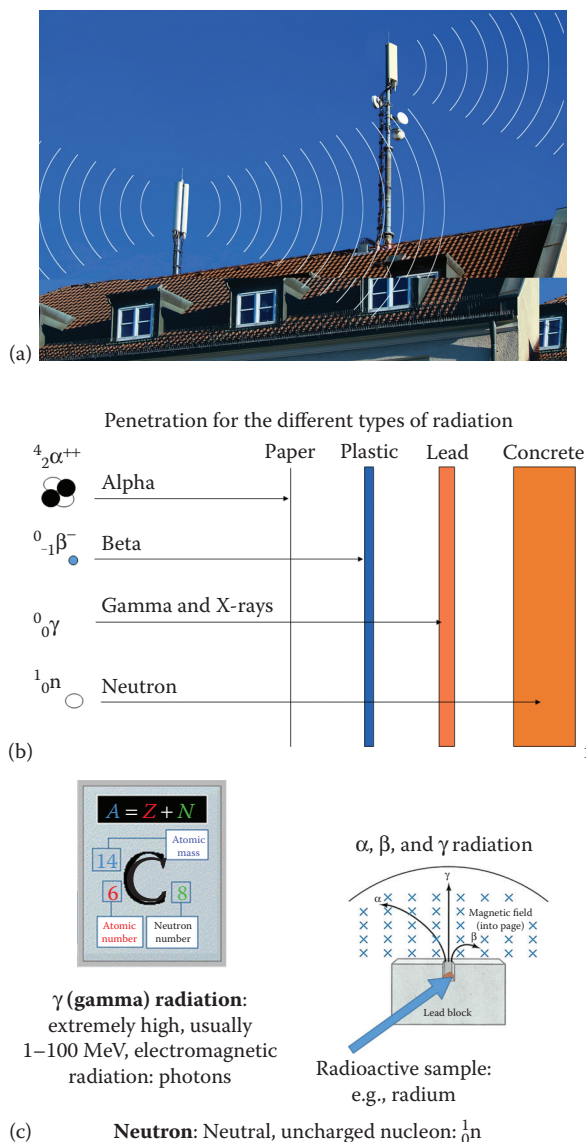


Figure R.4 Radiation: (a) antennas with simulated electromagnetic radiation, (b) penetration for different types of radiation, and (c) radiation physics showing the properties of α , β , and γ radiations.

Radiation belt

[astrophysics/astronomy, general] Partial shell of charged particles in orbit around EARTH, maintained by the earth's MAGNETIC FIELD. Several radiation belts are suspected, but the Van Allen radiation belts are verified and well described (*see* VAN ALLEN RADIATION BELTS; *also see* AURORA BOREALIS [i.e., NORTHERN LIGHTS]) (*see* Figure R.5).

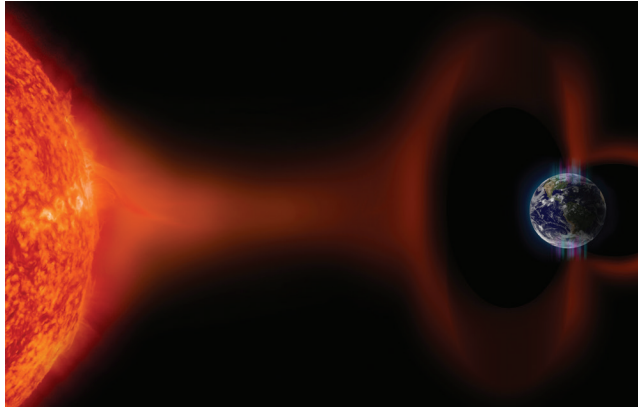


Figure R.5 Diagram of what a radiation belt around the Planet Earth may look like; with one of the consequences: the auroras.

Radiation coupling

[acoustics, optics] Coupling of acoustic or optical WAVE respectively. A principle that operates as a LINEAR FILTER which describes the transition between two lumped mechanical or optical components (*see* Figure R.6).



Figure R.6 Radiation coupling for acoustic waves. Relatively high-energy ultrasound is coupled into the skin for the disintegration of the mixture of fatty and connective tissue (e.g., collagen) in the treatment of cellulite. In order to avoid “burning” the skin a medium is applied between the transducer and the skin to maximize the transfer of acoustic energy to penetrate deep below the surface of the skin to perform the restructuring of the tissue based on radiation absorption at a location that is remote from the point of entry.

Radiation dose

[biomedical, nuclear] The emitted dose of PARTICLE and electromagnetic RADIATION resulting from ISOTOPE DECAY. The kind of radiation and respective ENERGY content will determine the biological impact, known as dosimetry and biological hazard. Radiation dose is generally measured in rem or millirem, accepted as a standard by the Nuclear Regulatory Commission (see DOSIMETRY; also see CARBON DATING) (see Figure R.7).



Figure R.7 Radiation dose meter, that is, Geiger counter, providing the exposure in Rads per hour.

Radiation force

[acoustics] Acoustic radiation force represents the interaction of an acoustic WAVE (longitudinal pressure wave) with an obstacle in its path. The MAGNITUDE of the FORCE (F) is directly correlated to the local AMPLITUDE (and respective intensity: I ; in $[\text{W}/\text{cm}^2]$) as $|F| = 2\alpha_{\text{abs}} I / v_s$, where v_s is the speed of SOUND in the medium with localized acoustic attenuation α_{abs} . The absorption coefficient is expressed in Neper per CENTIMETER (Np/cm) (see Figure R.8).

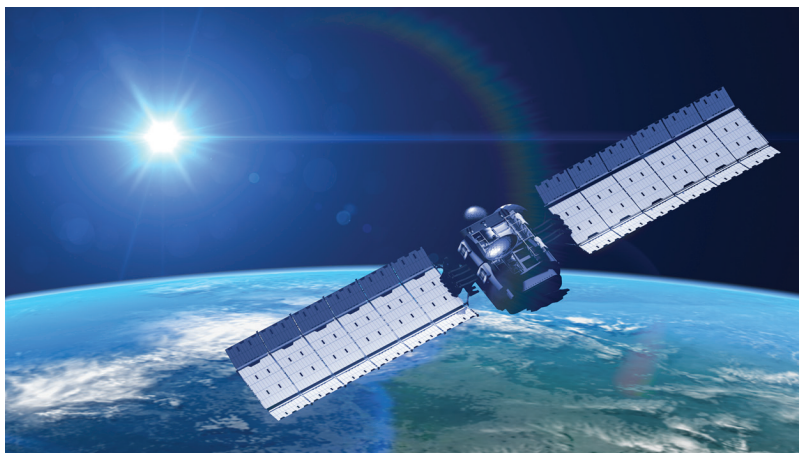


Figure R.8 Conceptual representation of solar wind, applying radiation force, acting on a long-range probe with large panels acting as solar sails. Note that for the solar radiation force to be effective the “sails” will need to be substantial since the effect is minimalistic, especially at expanding distance (diminished effect from the solar radiation pressure inversely proportional to the radius square).

Radiation hazards

[atomic, nuclear] Various kinds of radiation have different ENERGY content with specific biological and material consequences. The radiation ACTIVITY is one of the means of determining the potential for the energy content; disintegration rate. Another concept related to the energy content is the half-life. The originally adopted standard for radiation consequences is the number of ionizations produced by X-RAY or

gamma rays, since then replaced by the number of disintegrations per SECOND for a RADIOACTIVE ISOTOPE, measured in Becquerel ([Bq]). The biological damage potential is generally based on the ABSORBED DOSE, measured in Gray (old unit Rad). The risk for modifications to the genetic material: DNA, or causing burns resulting from a specific kind of exposure is expressed by the QUALITY FACTOR. The quality factor provides the dose equivalent exposure, which is a more quantifiable risk identifier for human risk. The quality factor (Q_r) for specific types of RADIATION is defined as follows: X-ray, gamma rays, and beta radiation $Q_r = 1$; high-energy photons have $Q_r = 10$; exposure to neutrons of unknown energy has a quality factor $Q_r = 10$; while ALPHA PARTICLES are considered to be the most hazardous with $Q_r = 20$. The following heuristic values for biological damage have been determined; absorbed dose and biological effect: 100 Gy results in virtually instantaneous death (hours); 12 Gy results in death within days; 6 Gy results in death within weeks; 1 Gy may be treated and the person may recover and survive (with residual biological damage); 0.5 Gy has no discernible biological effects; 0.25 Gy results in changes to the BLOOD structure; and at 0.05 Gy the first changes to blood are observed. Note that radiation exposure is cumulative. (Note: MARIE SKŁODOWSKA CURIE [1876–1934] suffered the consequences of her work with radiation, dying from radiation-inflicted damage to her biological functions.) In reference an average day yield exposure of 3 mSv/year; while a chest X-ray provides 6 mRem, and a lumbar spine CT 16 mSv. Background radiation exposure to every person on the PLANET results from the following sources: COSMIC RAYS; natural phenomena (e.g., ^{14}C {carbon dating} and radon); terrestrial sources (^{235}U); therapeutic devices (X-ray, etc.); various consumer products hold radioactive isotopes (e.g., tobacco: ^{210}Po ; welding rods: ^{222}Th ; certain mechanical watches have the dial “illuminated” by tritium or radium (old style); and smoke detectors: ^{241}Am), fall-out from nuclear weapons tests, radiation leaks from nuclear power plants; and the following sporadic and low importance (small MAGNITUDE) effects ISOTOPE research and AIR travel (*also see* RADIATION UNITS) (see Figure R.9).

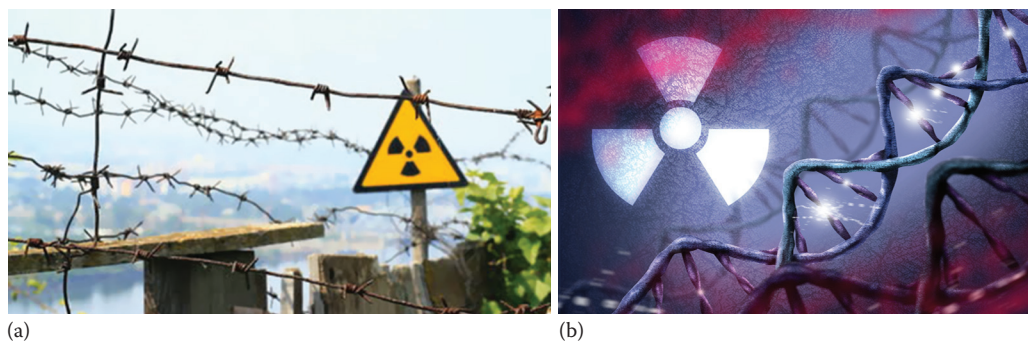


Figure R.9 (a) Radiation hazard warning sign near a nuclear power station and (b) graphical representation of how high-energy radiation may modify the genetic structure, resulting in cancer and/or death. Section of the abandoned city of Pripyat near Chernobyl in Ukraine (then Russia; as a matter of fact: CCCP/USSR) after a nuclear meltdown in the nuclear power plant.

Radiation therapy

[biomedical, energy, thermodynamics] Clinical, therapeutic procedures involving various types of RADIATION: charged particles (e.g., protons and electrons), X-RAY, and gamma rays to selectively cause the eradication of undesirable cells, specifically malignant cells of tumor structures. The radiation may be applied externally or internally. The external radiation is provided by specialized devices, whereas the internal radiation may be provided either from a confined RADIOACTIVE ISOTOPE (brachytherapy) or from the systemic release from an ISOTOPE introduced by ingestion or injection (e.g., radioactive iodine). The mechanism of action of generating CELL death as a therapeutic goal is in the restructuring of DNA form

external to the cell, or by means of creating secondary free radicals inside the cell without actual penetration subsequently resulting in cell death. The treatment of hypo- or hyper thyroidism by means of radioactive iodine is one of the most common and well-known methods. The thyroid treatment is relatively selective due to the affinity of the thyroid for iodine. Most cancer treatments are not selective about the targeted cells, and subsequently have a consequence of damaging and killing healthy cells as well, specifically in the direct vicinity of the tumor during external radiation, but more systemic (whole body) for isotope reagents released in the bloodstream (primary) or ingested for absorption in the BLOOD stream through the digestive system (secondary system). Radiation therapy may also be used for benign cancer when the cancer is causing secondary effects, for instance, causing pressure on vital organs due to the rapidly expanding cell volume, such as esophagus and spine. Therapeutic radiation to the brain may destroy the brain but the metastases of cancer spreading into the brain can potentially be regressed by radiation. One particularly specific and selective external means of radiation therapy is currently achieved by the CyberKnife. Brachytherapy may require special tools, such as catheters and needles and nanoparticles (see [Figure R.10](#)).



Figure R.10 Patient undergoing radiation therapy.

Radiation units

[atomic] The number of decaying nuclei per unit of time (disintegrations per SECOND) is measured in Becquerel ([Bq]; SI unit), alternatively the Curie is also found: $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$. The ENERGY of radiation is measured in electronvolt, ([eV]); the energy of an electron under a potential difference of 1 V. Examples are the electrons emitted from the carbon ISOTOPE ^{14}C have an energy of $157 \text{ keV} = 0.157 \text{ MeV}$ (beta radiation); gamma radiation from cesium (^{137}Cs) has an energy of 662 keV , and alpha radiation from Americium (^{241}Am) has an energy of 5.485 MeV . The ABSORBED DOSE is measured in Gray ([Gy]); old unit Rad. The conversion from Rad to Gray is $1 \text{ Rad} = 0.01 \text{ Gy}$. The exposure is measured in Coulombs per kilogram (SI: [C/kg]), with the old unit the Röntgen ([R]). The conversion equivalence from the Röntgen is $1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg}$. The dose equivalent has the quantity in Sievert (SI: [Sv]), while the old unit is Rem.

The Rem converts to the Sievert as $1\text{ Rem} = 0.01\text{ Sv}$. The “dose equivalent” exposure incorporates the type of radiation, expressed by the **QUALITY FACTOR**. The dose equivalent is a more quantifiable risk identifier for human risk (for instance, resulting in modifications to the genetic material: DNA, or causing burns) from exposure. For X-RAY RADIATION one Röntgen of radiation is approximately equivalent to 1 Rad with respect to human tissues. Under the old units gamma radiation yields $1\text{ R} \cong 1\text{ Rad} \sim 1\text{ Rem}$ (see [Figure R.11](#)).

Radiation activity units of measure

- The number of decaying nuclei per unit of time
- The Système International (SI) unit of radioactivity is the becquerel (Bq)
 - One Bq = 1 disintegration per second
- Non-SI unit of radioactivity is the Curie (Ci)
 - One Ci = 3.7×10^{10} transformations per s
 - One millicurie (mCi) = $3.7 \times 10^7 \text{ s}^{-1}$
 - One microcurie (μCi) = $3.7 \times 10^4 \text{ s}^{-1}$
 - $1 \text{ Bq} = 2.7 \times 10^{-11} \text{ Ci}$

(a)

Quantities and units

Quantity	Conventional	SI
Exposure	roentgen (R)	coulomb/kg
Absorbed dose	rad	gray (Gy)
Dose equivalent	rem	sievert (Sv)

(b)

Activity

- Activity is the number of transformations (or disintegrations) per time occurring in a radioactive material
- Conventional unit: curie (Ci)
 - $1 \text{ Ci} = 3.7 \times 10^{10}$ disintegrations per second
- International System (SI): Becquerel (Bq)
 - $1 \text{ Bq} = 1$ disintegration per second
- $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$

(c)

Activity—units: conventional vs. SI

Conventional system	SI system
• $1 \text{ milliCi} = 1/1000 \text{ Ci}$	• $1 \text{ kiloBq} = 1000 \text{ Bq}$
• $1 \text{ microCi} = 1/1,000,000 \text{ Ci}$	• $1 \text{ megaBq} = 1,000,000 \text{ Bq}$
• $1 \text{ kiloCi} = 1000 \text{ Ci}$	• $1 \text{ gigaBq} = 1,000,000,000 \text{ Bq}$
• $1 \text{ megaCi} = 1,000,000 \text{ Ci}$	

(d)

Energy units for measuring radiation

Radiation energies are typically measured in units of keV (1000 electron volts) or MeV (million electron volts)

Examples:

C-14 beta 0.157 MeV or 157 keV

Cs-137 gamma 662 keV

Am-241 alpha 5.485 MeV

(e)

Figure R.11 (a–e) Radiation unit configuration.

Radiative capture

[atomic] Capture of a low-energy proton (p) or NEUTRON (n) by the atomic nucleus, transforming the NUCLEUS into a RESIDUAL NUCLEUS in a highly excited state. The capture PARTICLE may not be expelled, leaving the nucleus to emit the excess ENERGY as gamma radiation (γ), while changing the ISOTOPE value. An example is the conversion of magnesium to aluminum through proton capture: $^{26}\text{Mg} + p \rightarrow ^{26}\text{Al} + \gamma$. Eventually, the (unstable) converted state will regress to the “GROUND” state when bombarded by gamma radiation during a process called PHOTODISINTEGRATION: $^{26}\text{Al} + \gamma \rightarrow ^{26}\text{Mg} + p$ (see Figure R.12).

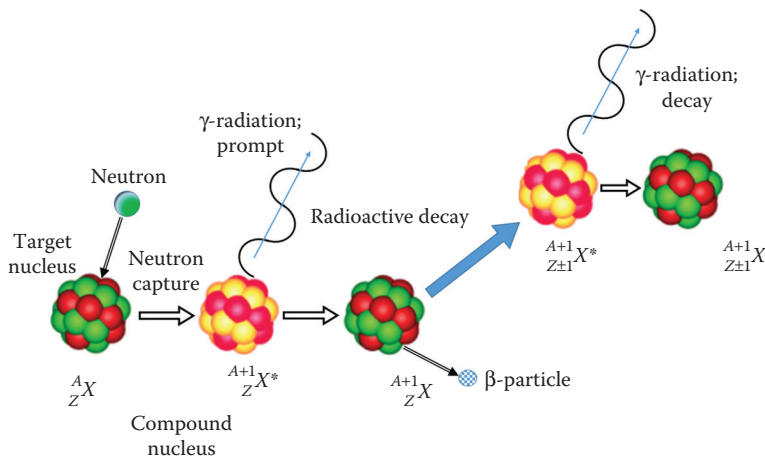


Figure R.12 Example of the process with respect to radiative capture for a neutron.

Radiative power

[biomedical, general] ENERGY transfer from one location to another. Calculated by the number of photons per SECOND ($\dot{n}$) at wavelength λ this yields: $P_{\text{radiative}} = (\dot{n}h/\lambda)c$, where with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT, and $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of LIGHT. Also known as RADIANT FLUX.

Radiative transfer

[astrophysics/astronomy, biomedical, energy] The transfer of ENERGY through the medium of electromagnetic RADIATION, also known as the radiative transfer equation (see EQUATION OF RADIATIVE TRANSFER).

Radio

[electronics, general] Device for receiving radio waves, which are emitted from radio stations. Sometimes also referring to the functional unit emitting the radio waves, the RADIO STATION (building with record players). Radio is subdivided in AMPLITUDE MODULATION (AM) and frequency modulation (FM). AM RADIO waves imply a perturbation applied to a CARRIER WAVE, where the perturbation encodes a selected portion of the audible frequency range (20 Hz–20 kHz), AM radio does not provide STEREO reception. In FM electromagnetic transmissions, the frequency of the carrier WAVE is changed within a narrow band to provide encoded embedded signals that can be decoded at the radio receiver. AM stations can be subdivided into short waves and long waves; operate in the frequency range 153 kHz to 26.1 MHz. Specifically, AM radio as found on the receiver operates from 535 to 1605 kHz. Long-wave radio SIGNAL as well as most AM signals across the frequency band will reflect off the IONOSPHERE, resulting in a long span of reception, long-wave radio specifically (153–279 kHz) can be received from the opposite side of the world under the appropriate weather conditions. FM radio primarily relies on line-of-sight reception (the tip of the ANTENNA is in theoretical view by the receiving location), this can extend in a flat topography for the geographic location for up to 30 km (primarily as a function of the radiant power supplied by the emitting station), apart from SATELLITE

transmission. FM radio generally operates in the frequency range 88–108 MHz. Due to the intricate process of FM and decoding process at the receiver, two signals can be transmitted simultaneously, offering stereo audio when two separate SPEAKER units are available and attached to the radio entity (see [Figure R.13](#)).

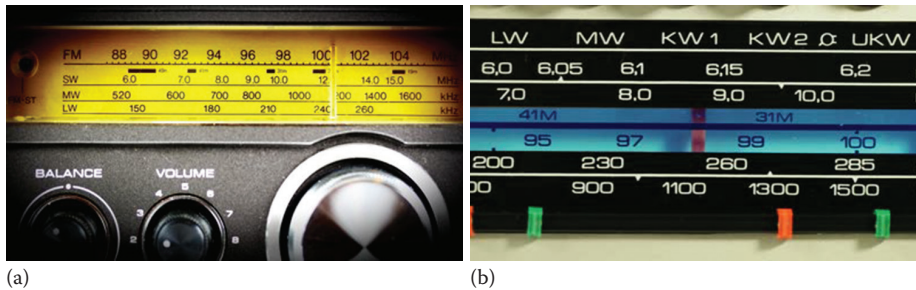


Figure R.13 (a) Analogue radio, showing the various wavebands: short wave (SW), medium wave (MW), long wave (LW), and frequency modulated (FM) and (b) analog radio display tuning panel which includes ultrashort wave band (UKW), primarily used in FM transmission.

Radio frequency (RF)

[biomedical, electronics] EMISSION SPECTRUM with the electromagnetic phenomenon. Radio frequency is in the wavelength range beyond INFRARED and microwave and in the same spectrum as RADIO and television waves, while shorter in wavelength than alternating power supplies/generators. The established spectral range is 3 kHz to 300 GHZ, where the high frequencies generally fall under microwave, it may still qualify as radio frequency. The Federal Communications Commission classifies radio frequency as the range of 9 to 275 kHz. Radio frequency RADIATION can be transmitted through cable more easily than the shorter wavelengths in the MICROWAVE regime, and is used for interstitial heat in biological therapeutic applications to provide elevated temperature-induced CELL death. Radio frequency is also used for navigation purposes as well as wireless communication (see [Figure R.14](#)).



Figure R.14 Radio frequency: radio-controlled remote operating helicopter.

Radio receiver

[general] There is a fundamental difference between analog and digital RADIO signal production and reception. The mechanism of action in analog modulation is continuous frequency modulation. In digital electromagnetic transmission and reception the encoding and decoding will still occur at the principal frequency, but the encoding will involve discrete pulse trains. With current technology the use of digital

mechanisms are more prevalent due to the reduced risks for distortion and NOISE compared to analog SIGNAL processing (*see* RADIO) (*see* [Figure R.15](#)).



Figure R.15 Radio receiver. Edwin Howard Armstrong (1890–1954) and his wife Esther Marion MacInnis on the beach with the “portable” radio designed and built for his wife, on Palm Beach, Florida, in 1923. The radio was Edwin Armstrong’s portable superheterodyne. Earlier “portable radios” are on record.

Radio station

[electronics, general] Building with record players, CD-players (MP3, MP4, etc.), digital storage devices (computer hard drives, memory sticks, etc.), and one or more microphones, that are connected electronically to an encoding device that embeds the audio signals in electromagnetic RADIATION that is conveyed to an ANTENNA that radiates the electromagnetic SIGNAL in all directions; alternatively routed to SATELLITE stations for satellite transmission. The first RADIO operation was in 1906, only AM. The FM radio principle was patented in 1933 by Edwin Howard Armstrong (1890–1954), an electrical engineer from the United States, followed in 1937, the first experimental radio station (W1XOJ) in the United States providing the first frequency modulated radio transmission, followed in 1948 with FM TRANSMISSIONS in Germany under newly implemented waveband plans. In 1958 English radio transmissions were experimentally used for STEREO transmissions. Note that the first two-channel audio system had already been introduced in 1881 by Clément Ader (1841–1925) in Paris (*see* [Figure R.16](#)).



Figure R.16 Example of a radio station in the United States.

Radioactive decay

[atomic, computational, energy, general, nuclear] Radioactive decay will depend on the original state of the ISOTOPE or unstable NUCLEUS. The determining factor is relying on PROTON or NEUTRON deficiency. The kinds of DECAY recognized are the following. ALPHA PARTICLE decay [α], the PARTICLE emitted during decay resembles a helium nucleus consisting of two neutrons and two protons: ${}^A_ZX \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2\text{He}$. The second form is BETA PARTICLE decay [β^-]: ${}^A_ZX \rightarrow {}^A_{Z+1}Y$, where the beta particle is in all characteristics identical to an electron. The other mechanism of decay is represented by beta-plus radiation (also referred to as positron emission) [β^+]: ${}^A_ZX \rightarrow {}^A_{Z-1}Y$. Gamma radiation is another form of radioactive decay due to annihilation, where a positron (beta-plus particle) and an electron (equivalent beta particle) collide and form a pair of gamma photons that are emitted at perfectly opposite directions. Each gamma PHOTON has an ENERGY of 0.511 MeV. ELECTRON CAPTURE is a form of RADIATION where an electron is captured by an unstable nucleus that does not have enough energy to spontaneously decay by positron emission. The convergence of a proton and the captured electron are transformed into a neutron and a NEUTRINO: $p_{\text{proton}} + e^- = n_{\text{neutron}} + \bar{\nu}$. The resulting vacancy in the electron shell will result in X-RAY emission. The CHARACTERISTIC X-RAY radiation associated with the removal of the electron will with great PROBABILITY come from K-shell decay. In the electron capture process gamma radiation may also occur. In certain cases, depending on the energy configuration the release of gamma energy will be captured by an orbital electron, which is internally released, indicated by the mechanism of action of INTERNAL CONVERSION (see Figure R.17).

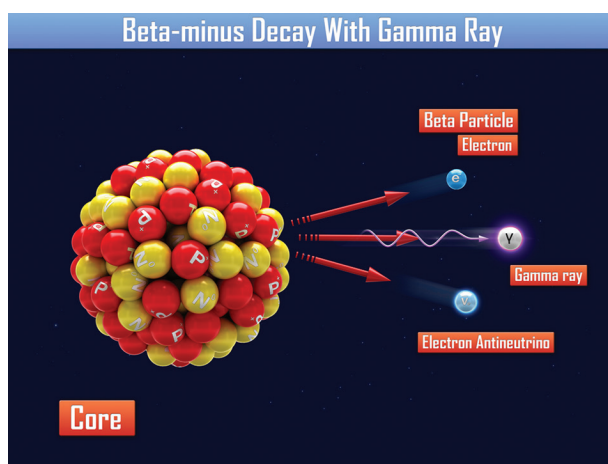


Figure R.17 Radioactive decay example.

Radioactive decay chain

[nuclear] RADIOACTIVITY was discovered by ANTOINE HENRI BECQUEREL (1852–1908) in 1896, but the phenomenon was named by MARIE SKŁODOWSKA CURIE (1876–1934) around 1903. Chain of discrete isotopes that are formed during the RADIOACTIVE DECAY process. The chain represents the series of events and

product from naturally radioactive of artificially produced RADIOACTIVE ISOTOPE to the final stage over the extended time duration of the cumulative half-life intervals of all the intermediate steps (see Figure R.18).

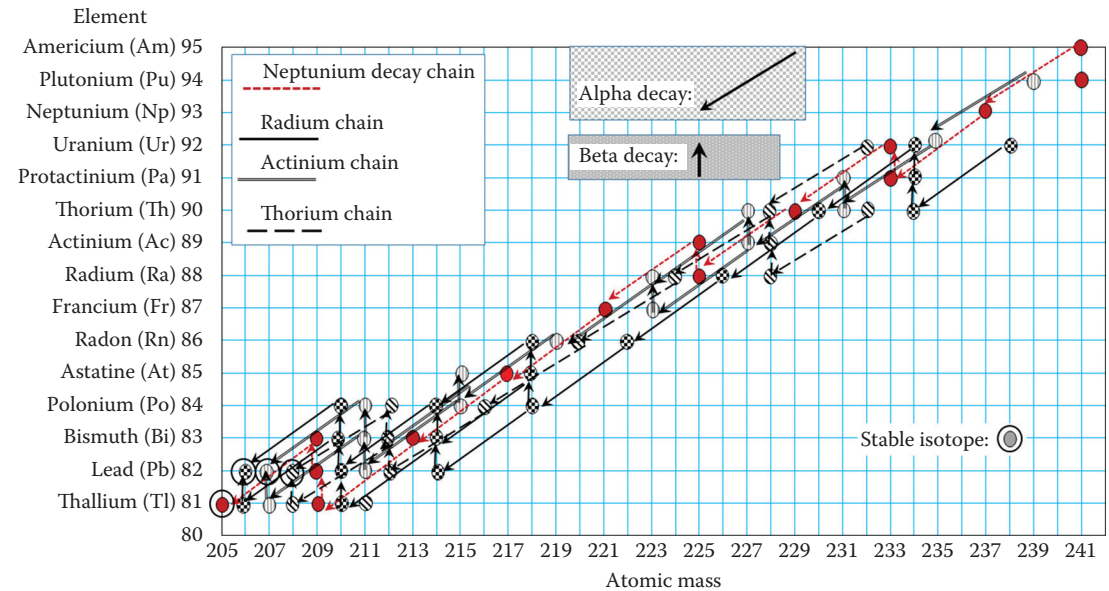


Figure R.18 Radioactive decay chain.

Radioactive decay constant (λ_{decay})

[atomic, nuclear] Constant indicating the rate of isotope DECAY, representing the proportional reduction in ISOTOPE (N_{isotope}) with respect to the original quantity, or ACTIVITY at initiation of isotope (N_0) over time of activity (t): $dN = -\lambda_{\text{decay}} N dt$, or $N(t) = N_0 e^{-\lambda_{\text{decay}} t}$. The HALF-LIFE (τ_{decay} , also found as $T_{1/2}$) of the isotope follows directly from the time lapse to decay to half the original quantity $N(\tau_{\text{decay}}) = (1/2)N_0$, yielding $\tau_{\text{decay}} = T_{1/2} = \ln 2 / \lambda_{\text{decay}} = 0.693 / \lambda_{\text{decay}}$ (see Figure R.19).

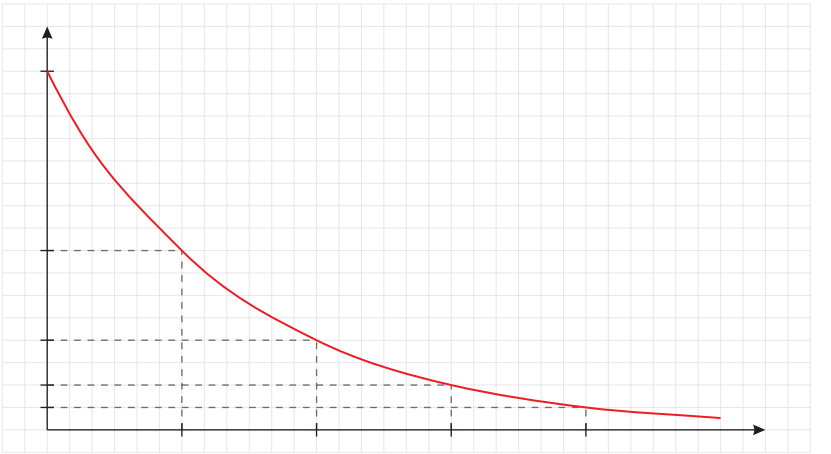


Figure R.19 Graphical interpretation of the radioactive decay constant in the time lapse for disintegration.

Radioactive decay law

[atomic, biomedical, energy, nuclear] *see* RADIOACTIVE DECAY CONSTANT *and* RADIOACTIVE TRANSFORMATION.

Radioactive isotope

[atomic, nuclear] Atom with identical chemical behavior as a known ELEMENT but with a different mass. Isotopes are generally radioactive with an associated half-life. The most well-known radioisotope is carbon-14, the ISOTOPE of carbon-12. Carbon-14 occurs naturally in all carbon-based life forms due to the chemical exchange during the lifetime of the biological entity, for example, consumption of carbohydrates. Carbon-14 is specifically known for determination of the AGE of the “deceased” biological object, based on the RADIOACTIVE DECAY. The half-life of ^{14}C is 5,730 years with electron emission, which limits the use for age determination to approximately 50,000 years; with potential enhancements in the detection technique stretching the span to 100,000 years (e.g., accelerator technique). The ratio of ^{14}C to ^{12}C is a relative constant at 1.3×10^{-12} in a living environment. Other examples of naturally occurring isotopes, with respective HALF-LIFE ($\tau_{1/2}$) and decay process are uranium-238, $\tau_{1/2} = 4.5 \times 10^9$ years, alpha-particle (α_d); tritium-3, $\tau_{1/2} = 12.26$ years, ELECTRON (e^-); cobalt-60, $\tau_{1/2} = 5.24$ years, e^- ; iodine-131, $\tau_{1/2} = 8$ days, e^- ; and radon-222, $\tau_{1/2} = 3.82$ days, α_d . It is also known as RADIOISOTOPE, or ISOTOPE (see Figure R.20).

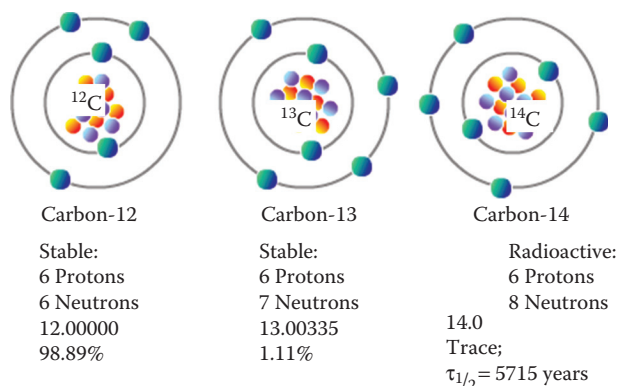


Figure R.20 Carbon isotopes.

Radioactive transformation

[atomic, nuclear] The random process of nuclear transmutations of ELEMENT, subject to the WEAK FORCE. The transformation process can be expressed as a STOCHASTIC PROCESS describing the overall likelihood of the occurrence of a change in elemental structure over TIME (t) expressed as $N(t) = N_0 e^{-t/\tau_{1/2}}$, with $\tau_{1/2}$ the RADIOACTIVE DECAY half-life, and N_0 the initial quantity of radioactive material; known as the LAW OF RADIOACTIVE TRANSFORMATION. The following transformation processes are available: ELECTRON DECAY, POSITRON DECAY, ALPHA DECAY, gamma decay, orbital ELECTRON CAPTURE, nucleon energy transfer to GROUND STATE, INTERNAL CONVERSION (NUCLEON to electron), next to spontaneous FISSION, double BETA DECAY (specifically related to ^{92}Mo and ^{100}Mo), and cluster decay (*see* RADIOACTIVITY).

Radioactive waste

[atomic, nuclear] Refuse resulting from the commercial use of radioactive isotopes. Radioactive waste is produced by hospitals during cancer therapy, in the production of several consumer goods and the generation of ELECTRICITY by means of nuclear power plants. A byproduct of coal burning factories is slurry (ash) that is also radioactive due to the uranium and thorium content in coal (see [Figure R.21](#)).



Figure R.21 Radioactive waste handling and disposal.

Radioactivity

[atomic, nuclear, quantum] The process whereby certain nuclides undergo spontaneous atomic disintegration in which ENERGY is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one or more types of RADIATION, such as ALPHA PARTICLES, BETA PARTICLES, and gamma radiation (*also see URANIUM and ISOTOPE*) (see [Figure R.22](#)).

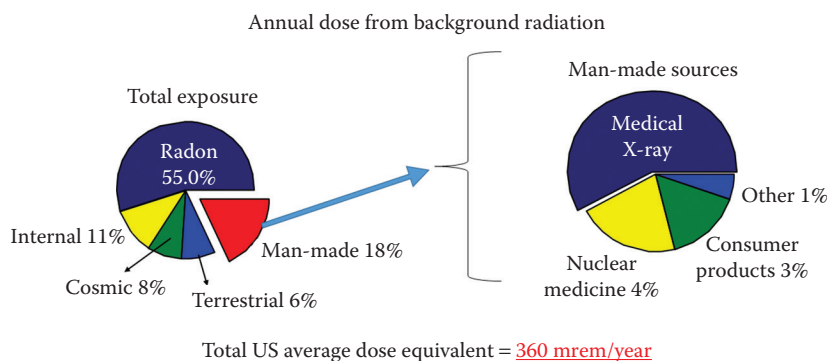


Figure R.22 Some commonly occurring low-level emission radioactive consumer goods.

Radioastronomy

[astrophysics/astronomy, atomic] Branch of astronomy that uses the coherent aspects of electromagnetic RADIATION from galactic bodies for identification and determination of location. Generally, the sensing mechanism involves a RADIO telescope arranged in an INTERFEROMETER setting. Next to several multi-dish ANTENNA stations in discrete locations all over the world, the independent locations are collaborating to form a global-sized interferometer. One of the independent antenna arrays is the very large array on the plains of San Agustin, between the towns of Datil and Magdalena in New Mexico, consisting of 27 antennas, each

with a diameter of 25 m, configured in a Y-setting with arm length of 21 km. The very large array has a spatial RESOLUTION of 0.08 arcsec (see [Figure R.23](#)).



Figure R.23 Examples of radio telescopes searching the universe for radiographic (electromagnetic) information about structural composition of remote galactic objects next to potential radio emissions from artificial sources indicating the existence of extraterrestrial life. In the United States, the search for extraterrestrial life is categorized under SETI: search for extraterrestrial intelligence, in which the United States is executed by groups at, for instance, Harvard University, Cambridge, Massachusetts; the University of California, Berkeley, California, and the SETI Institute in Mountain View, California.

Radiography

[imaging] Transcorporeal imaging technique using X-RAY RADIATION. It is also known as radiographic analysis and radiography imaging (*also see CT-IMAGING and X-RAY IMAGING*) (see [Figure R.24](#)).

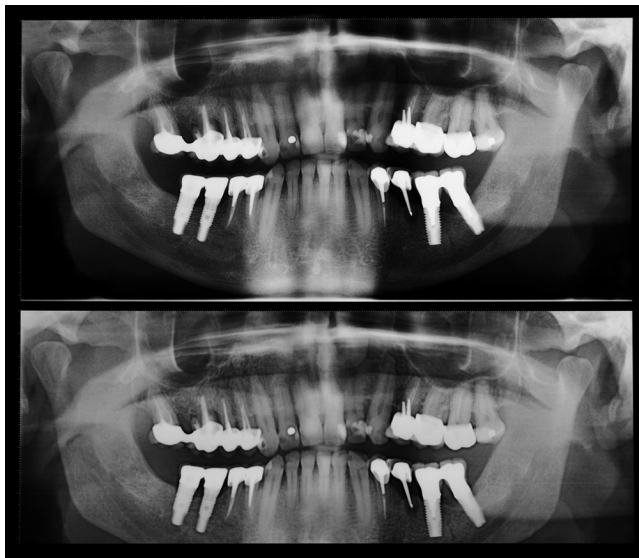


Figure R.24 Extra-oral radiographic view showing the placement and outline of the teeth, sometimes to be used for identification purposes. Sometimes also referred to as fluoroscopy, based on the scintillation elements recording the transmitted X-ray radiation and converting it in electromagnetic radiation that can be detected by electronic sensor units. The collected signals as a function of location and time of detection are ordered by computational techniques to render a reconstructed image based on attenuation for line of flight.

Radioisotope

[atomic, biomedical, general, nuclear] *See* ISOTOPE.

Radionuclide

[atomic, biomedical, nuclear] *See* NUCLIDE.

Radiopharmaceutical

[biomedical, chemical] RADIOACTIVE ISOTOPE used for tagging and imaging of physiological and anatomical features and phenomena, primarily applied in positron emission TOMOGRAPHY. One of the most used radiopharmaceuticals is fludeoxyglucose (FDG: $C_6H_{11}^{18}FO_5$) used in gauging the METABOLIC ACTIVITY related to cancer, HEART disease as well as epilepsy due to its equivalence with standard dietary GLUCOSE (see Figure R.25).

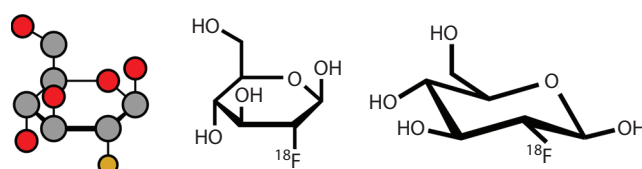


Figure R.25 Chemical diagram of radiopharmaceutical: fludeoxyglucose ^{18}F .

Radium ($^{226}_{88}Ra$)

[atomic, general, nuclear] Radioactive ELEMENT discovered by MARIE (MANYA) SKŁODOWSKA CURIE (1867–1934) and her husband PIERRE CURIE (1859–1906) approximately in 1902. Radium, generally found in the GROUND, decays to radon in the ground.

Radius of gyration (R_g)

[atomic, biomedical, fluid dynamics, solid-state] Parameter used to describe the characteristic dimension that apply to a POLYMER chain in polymer PHYSICS, defined as

$$R_g = \sqrt{\left[(1/n) \sum_{i=1}^n (r_i - r)^2 \right]} = \sqrt{\left[(1/2n^2) \sum_{i,j}^n (r_i - r_j)^2 \right]},$$

where r_i signifies the DISTANCE to the “central axis” of the polymer; representing the center of mass as a function of longitudinal location for location i , and r the mean radius to the central axis for the collective assembly of monomers; also with respect to the interspatial distance for the respective monomers (defined in the root mean square for $r_i - r_j$). Alternatively, in fluid-dynamic applications of buoyance the radius of gyration signifies the configuration of a floating object, given by the root mean square distance for a representative number of locations on the surface of the objects and associated parts with respect to the CENTER OF GRAVITY over the length of the object: $R_g = \sqrt{(I/A)}$, where I is the MOMENT OF INERTIA of the object in the direction of roll (predominantly perpendicular to the long axis of the body), and A the surface area of the buoyant object under the LIQUID surface.

Radon ($^{222}_{86}\text{Rn}$)

[atomic, general, nuclear] Radioactive ELEMENT formed by ALPHA DECAY of radium. Radon GAS is often found in the basement of houses due to the way radon is formed in the GROUND. Radon radiates by alpha decay and provides approximately 55% of all background RADIATION (see [Figure R.26](#)).

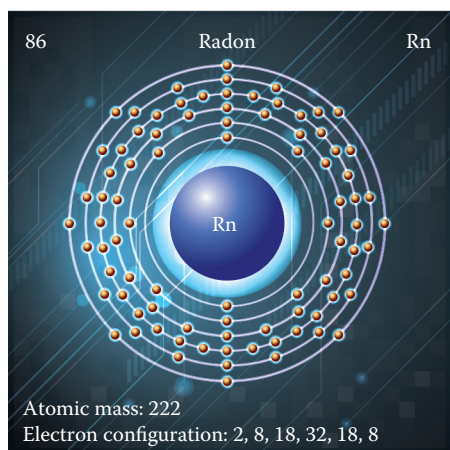


Figure R.26 The element radon and the theoretical electron configuration.

Rain

[energy, fluid dynamics, general, geophysics] Precipitation in LIQUID form, droplets of condensate water from clouds; the condensate water VAPOR reaches a volume that becomes subject to gravitational attraction, overcoming the BUOYANCY (see [Figure R.27](#)).



Figure R.27 Liquid precipitation.

Rain gauge

[energy, fluid dynamics, general, geophysics] Device used to determine a physical phenomenon in the lower part of EARTH'S ATMOSPHERE directly related to LIQUID precipitation (see [Figure R.28](#)).



Figure R.28 Rain gauge.

Raisin-pudding atom

[general] See **BOHR ATOM MODEL**.

Raman, Chandrasekhara Venkata, Sir (1888–1970)

[energy, optics] Indian scientist and philosopher. Sir Raman received Nobel Prize for Physics with regard to his work on the molecular SCATTERING of LIGHT in 1930. In 1921 Professor Chandrasekhara V. Raman and his students discovered that an incident light beam transmitted through a LIQUID resulted in a spectrum that not only included the original light but also secondary radiation at shifted wavelengths. The original experimental setup passed sunlight through an optical filter to produce a polarized incident light beam that was then transmitted through the sample material. The emerging scattered light beam was then passed through a second optical filter and the resulting spectrum was observed visually. From these initial experiments it was determined that the intensity of the resulting secondary RADIATION was dependent on both the frequency and the POLARIZATION of the light beam incident to the sample (see [Figure R.29](#)).



Figure R.29 (a,b) Sir Chandrasekhara Venkata Raman (1888–1970).

Raman scattering

[nuclear, optics, solid-state] Inelastic SCATTERING of photons, first described in a LIQUID turbid medium by SIR CHANDRASEKHARA VENTAKA RAMAN (1888–1970) and Kariamanickam Srinivasa Krishnan (1898–1961) in liquid in 1921. The effect was confirmed for scattering in crystals by Grigory Samuilovich Landsberg (1890–1957) and Leonid Isaakovich Mandelshtam (1879–1944) in 1928. In contrast to ELASTIC SCATTERING, where the ENERGY is conserved, in Raman scattering portion of the PHOTON energy is transferred to the molecular bindings, thus revealing details about the energy of the atomic–molecular structure based on the emitted INFRARED spectrum. For the constituents of a CHEMICAL COMPOUND with N atoms, there are a total of $3N$ DEGREES OF FREEDOM with respect to rotation, stretch, and bend (scissor action) for the motions of the MOLECULE. For a linear molecule the total number of vibrational modes is $3N-5$, whereas for a complex structure the vibrational modes add up to $3N-6$. This principle is applied to gas CHROMATOGRAPHY for molecular analysis. The spectral profile will be composed of Rayleigh scatter, Stokes and anti-Stokes scatter frequency shifts (cm^{-1} scale), and is referred to as the Raman spectrum. The shifts in spectral peaks are indications of the energy changes with respect to GROUND STATE of the molecule, and define the BINDING ENERGY profile and can be used to identify the chemical structure with the help of look-up tables.

Also known as the Raman effect. Also described as RAMAN SPECTROSCOPY with respect to the physical detection of the transition processes (see [Figure R.30](#)).

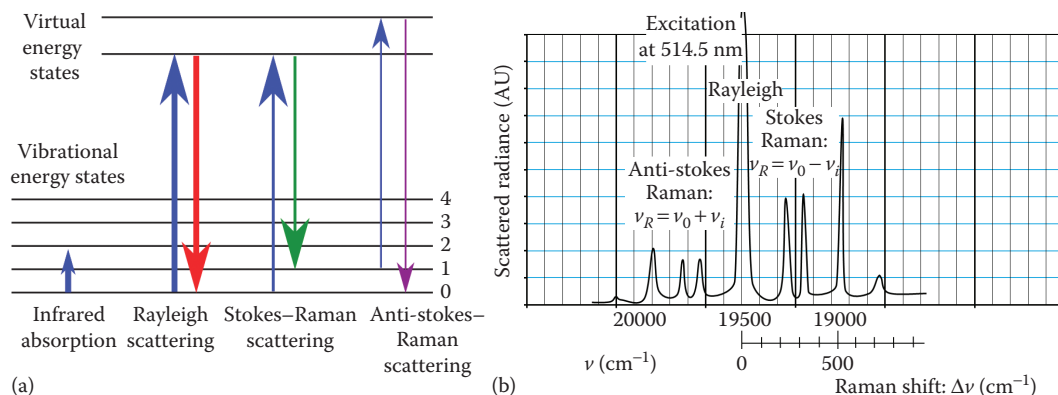


Figure R.30 (a,b) Raman scattering and associated Raman spectroscopy. The Raman spectrum is composed of sharp and narrow peaks. The peaks are on either side of the excitation line resulting from laser irradiation (excitation). The peaks are referred to as Stokes and anti-Stokes lines. The graph represents the Stokes and anti-Stokes Raman spectral lines for the chemical compound CCl_4 , under excitation irradiation by a 514.5 nm argon ion laser line. The frequency differences between the excitation radiation and the Raman scattered radiation are called the Raman shift. Raman shifts are reported in units of wavenumber (cm^{-1}) and are defined by the Raman shift: $\Delta = (1/\lambda_0) - (1/\lambda_R)$ [cm^{-1}] resulting from laser irradiation with wavelength λ_0 , with the resulting Raman radiation at wavelength: λ_R .

Raman spectroscopy

[atomic, nuclear, optics] See **RAMAN SCATTERING**. Also known as **RAMAN SPECTRA**.

Ramsay, William Mitchell, Sir (1852–1916)

[general] Scientist from Scotland (Great Britain), known for his discovery of helium on EARTH, specifically in uranium bearing minerals as well as the description of noble gases (inorganic chemistry) starting in approximately 1885. His work and the work of **FREDERICK SODDY** (1877–1956) showed that the helium originated from radium, produced in a **DECAY** process. They however did not describe the atomic structure of helium just yet. Sir Ramsay received the Nobel Prize in Chemistry for his work on noble gases in 1904. Sir Ramsay discovered and defined argon, helium, krypton, neon, and xenon (see [Figure R.31](#)).



Figure R.31 Sir William Mitchell Ramsay (1852–1916).

Random walk

[biomedical, computational] Stochastic principle in discrete PROBABILITY distribution with respect to the SCATTERING of photons in a turbid medium such as tissue. The concept of random walk is most frequently approached through computer simulation mechanisms using a principle called “Monte Carlo” analysis, relying on a probability distribution of the scattering events in this case using THEORY OF LARGE NUMBERS. Compare to FINITE ELEMENT ANALYSIS (see [Figure R.32](#)).

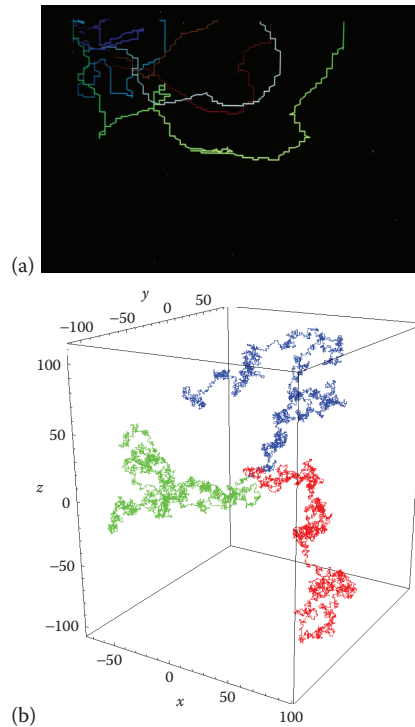


Figure R.32 Representation of the principle of random walk (a) in two-dimensional projection for 5 photons and (b) for three events (e.g., photons, molecules, etc.) in three-dimensional diagram, generated by means of computer simulated ray-tracing.

Rankine

[biomedical, thermodynamics] Unit of measure of ABSOLUTE TEMPERATURE designed by WILLIAM RANKINE (1820–1872). In comparison the Kelvin and degrees Celsius are relative scales.

Rankine, William John Macquorn (1820–1872)

[general, solid-state, thermodynamics] Scottish scientist (physicist/engineer), who made significant contributions to the development of the thermodynamic theoretic base (see [Figure R.33](#)).



Figure R.33 William John Macquorn Rankine (1820–1872). (Courtesy of University of Glasgow, Glasgow; “Memorials of the Old College of Glasgow”—http://encore.lib.gla.ac.uk/iii/encore/record/C__Rb1168827?lang=eng.)

Rankine cycle

[thermodynamics] Process that is fundamentally reversible pertaining to the temperature-specific entropy loop for a system of bulk flow states. The process consists of four segments; the first segment is isobaric heating, followed by an **ISENTROPIC** interval of **EXPANSION** to the two-phase system, the third segment involves the isobaric condensation under constant temperature, with the final stage returning to the original format under isentropic compression under **MECHANICAL ENERGY** resulting from the compression by piston with work rate $\dot{W}_c^{\leftarrow}$. The efficiency (η_{eff}) of the Rankine cycle is a function of the specific enthalpy (h_i) of the

various stages (4) in the process: $\eta_{\text{eff}} = \left[(h_4 - h_5) - (h_1 + h_6) \right] / (h_4 - h_1) = 1 - \left[(h_5 - h_6) / (h_4 - h_1) \right]$, introduced based on the work of WILLIAM RANKINE (1820–1872) (see Figure R.34).

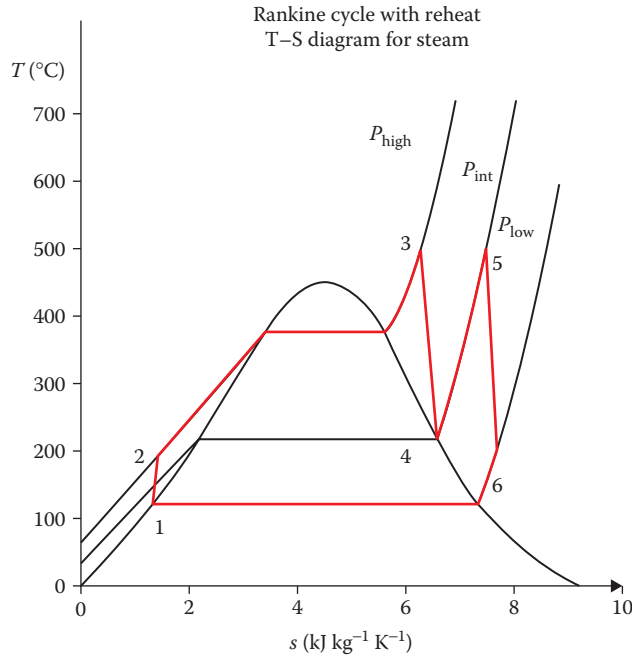


Figure R.34 Graphical representation of the Rankine cycle.

Rankine–Hugoniot equations

[fluid dynamics] Equation describing the physical properties during a SHOCK WAVE propagating with shock WAVE velocity v_s , undergoing volumetric changes (specific volume V_{sp}), and velocity of the mechanism of expansion (e.g., piston, breaking plate, moving surface) v , with $\square_0$ describing the initial state, pertaining to CONSERVATION OF MASS: $(V_{\text{sp},0} - V_{\text{sp}})/V_{\text{sp},0} = (v - v_0)/v_s$; as well as the conservation of momentum under PRESSURE (P) change: $P - P_0 = v_s \left[(v - v_0)/V_{\text{sp},0} \right]$; and the CONSERVATION OF ENERGY, where the EXPANSION provides kinetic ENERGY (KE), combined with the potential energy (U) as total energy (E): $E - E_0 = (V_{\text{sp},0} - V_{\text{sp}})(P + P_0)/2$. The Rankine–Hugoniot equations define the respective final states of the shock compression for the medium with an initial state. The graphic representation of the pressure versus the volume for the shock wave is referred to as the “Hugoniot.” With the use of the Rankine–Hugoniot equations the shock wave can be determined when the initial conditions are known and any two of the other five components in the equation can be measured. The expansion velocity is most commonly measured. Related to the shock wave the following relationships apply. For the expansion the correlation to the MACH NUMBER (M), SPECIFIC HEAT (c_p ; respectively c_v), and respective specific heat ration: $\gamma_s = c_p/c_v$, provides $P/P_0 = \left[2\gamma_s M^2 - (\gamma_s - 1) \right] / (\gamma_s + 1)$. For the specific volume this yields $V_{\text{sp}}/V_{\text{sp},0} = \left[(\gamma_s - 1)M^2 + 2 \right] / \left[(\gamma_s + 1)M^2 \right]$. Whereas the IDEAL GAS LAW provides the TEMPERATURE (T) relation during a shock-wave as $T/T_0 = PV/P_0V_0$.

Raoult, François-Marie (1830–1901)

[chemical, thermodynamics] A chemist from France. François-Marie Raoult defined the MIXING of gases (and this may under strict conditions also apply to solutions) as RAOULT'S LAW. Additional work by Raoult described the lowering of the freezing point (T_{freeze}) as a result of adding a SOLUTE to a LIQUID, proportional to the molecular concentration: $T_{\text{freeze}} = M\mathcal{A}_{\text{temp}}$, where M is the MOLECULAR WEIGHT of the dissolved component and $\mathcal{A}_{\text{temp}}$ the molecular lowering of the FREEZING temperature; sometimes referred to as the general law of the freezing of solutions (see [Figure R.35](#)).

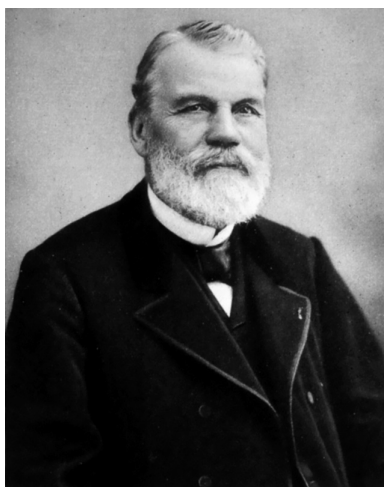


Figure R.35 François-Marie Raoult (1830–1901). (Courtesy of Zeitschrift für Physikalische Chemie, Vol. 27, 1898.)

Raoult's law

[thermodynamics] The partial VAPOR PRESSURE for each of the components in a mixture is equal to the vapor pressure of the individual constituent at that temperature multiplied by the respective MOLE fraction in the mixture. Introduced by FRANÇOIS-MARIE RAOULT (1830–1901) in 1882.

R

Rapid prototyping

[biomedical, general, mechanics] The process of “printing” a three-dimensional design with composite material in a rapid process without the requirements for a mold, such as those used in injection molding, generally based on a Voxel-based construction using incremental steps of micrometers or millimeters; however, single molecular construction is also being developed for medical device and nanoscale intervention. Rapid-prototyping uses computer aided design (CAD-drawings) as the input for the process to “write” the construction in a stereolithographic format. The composite material is selectively positioned in pre-designated locations in three-dimensional space and cured by a process that depends on the material choice, sometime requiring laser LIGHT, sometimes OXIDATION or EVAPORATION by means of outside AIR. Rapid prototyping is used to create either scale models for show-and-tell or full-sized working devices, on small profile, in mass production up to several CENTIMETER in size. The size of rapid-prototyping designs is rapidly increasing to construct devices in meter size and larger. Several different techniques are available, ranging from laser sintering to epoxy molding. The initial introduction of rapid-prototyping was in the late 1980s. Also known as 3D printing, since the process has outgrown the “prototyping” stage. This rapid-prototyping is gently replacing computer NUMERICAL control machining since composite materials are approaching and exceeding METAL strengths (see [Figure R.36](#)).

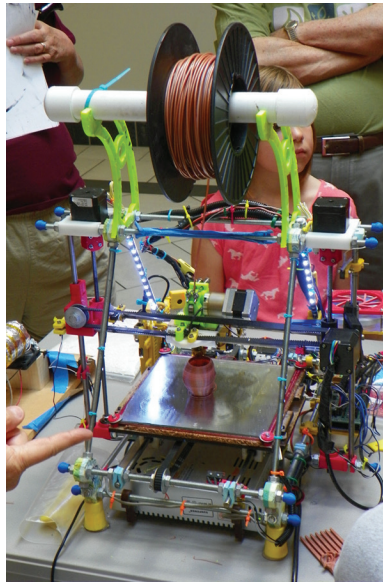


Figure R.36 Rapid prototyping machine made out of LEGO® bricks, fully functional, connected to a computer and supplied with polymer substrate.

Rarefaction

[general] Reduction in molecular or PARTICLE density, or alternatively for a solid in space this may equate to an EXPANSION of the material, respectively stretch of a spring. Opposite of compression. For gases rarefaction is the opposite to condensation (see [Figure R.37](#)).

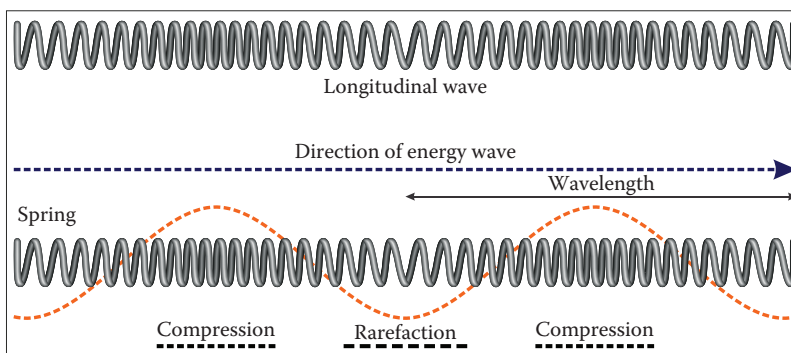


Figure R.37 Rarefaction.

Rasmussen, John (1926–)

[nuclear] Chemist from the United States. John Rasmussen provided significant details to the understanding of the nuclear structure from both experimental and on theoretical basis (see [Figure R.38](#)).



Figure R.38 John Rasmussen (1926–).

Rayleigh, Lord, a.k.a. John William Strutt (1842–1919)

[general, optics] Scientist from Great Britain. Lord Rayleigh's work describes the interaction of LIGHT with small particles, providing scattering at wavelengths generally smaller than the PARTICLE size. The Rayleigh scattering explains the spectral profile for the colors of the sky with respect to the position of the SUN and the pollutants and water droplet size in the ATMOSPHERE. The work of Lord Rayleigh was based on the experimental observations from JOHN TYNDALL (1820–1893), resulting is the RAYLEIGH SCATTERING theory in 1871. The Rayleigh scattering theory compares to the MIE SCATTERING from long wavelengths, described by GUSTAV MIE (1868–1957) in 1908 (see [Figure R.39](#)).

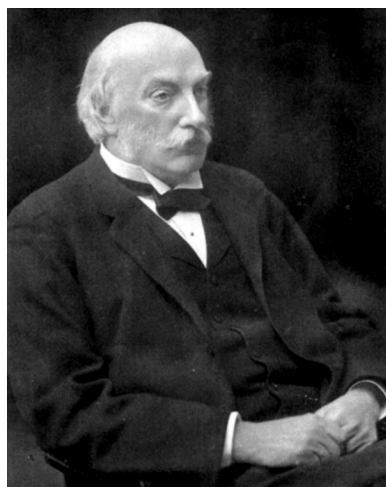


Figure R.39 Lord Rayleigh, a.k.a. John William Strutt (1842–1919).

Rayleigh criterion

[acoustics, optics] The angular separation ($\sin \theta \cong \theta$) that allows for independent recognition of two closely spaced objects or LIGHT sources (primary or secondary) as a function of wavelength (λ) as observed through an APERTURE with diameter D defined as $\theta = 1.22(\lambda/D)$, with corrections for edge effect of a circular opening ($\theta = \lambda/D$ for straight edges) (see **ABBE CRITERION** and **AIRY DISK**) (see [Figure R.40](#)).

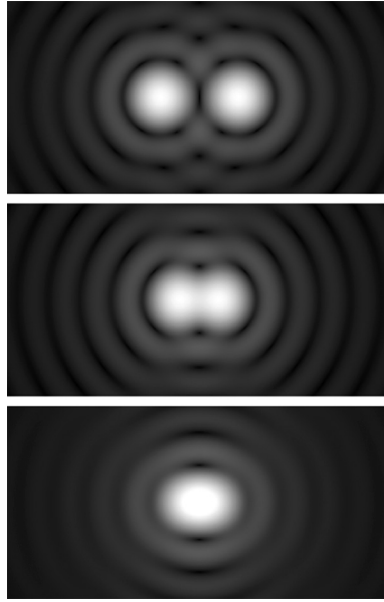


Figure R.40 Rayleigh criterion.

Rayleigh emission law

[general, optics] Black-body RADIATION as a function of wavelength (λ) or FREQUENCY (ν): $I_{\nu,T}(T, \nu) = (2\pi c/\lambda^4) k_b T = (2\pi \nu^2/c^2) k_b T$, where $\lambda = c/\nu$ is WAVELENGTH, ν the frequency, c the speed of LIGHT, k_b is the BOLTZMANN CONSTANT, T the TEMPERATURE (in Kelvin). Also known as the Rayleigh–Jeans emission Law (see [Figure R.41](#)).

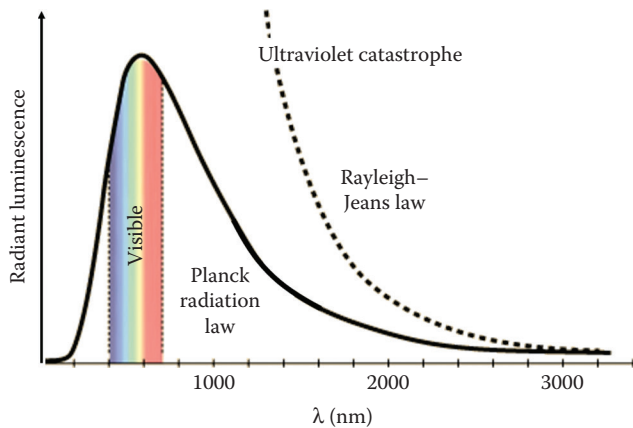


Figure R.41 Rayleigh (Rayleigh–Jeans) emission law.

Rayleigh flow

[fluid dynamics, thermodynamics] Flow condition with respect to adiabatic flow in a tube with constant cross-sectional area under flow velocity approaching or exceeding the MACH NUMBER. The flow under these conditions is subject to the stagnation temperature (T_s) and the Mach number (Ma) changes as described by $dM^2/M^2 = \left[\frac{(1 + \gamma_s Ma^2)}{(1 - Ma^2)} \right] \left(1 + \left[\frac{(\gamma_s - 1)}{2} \right] Ma^2 \right) (dT_0/T_0)$, where $\gamma_s = c_p/c_v$ is the SPECIFIC HEAT ratio; for the specific heat (c_p at constant pressure; respectively c_v at constant volume). The associated change in ENTROPY (S) is $\Delta S = \Delta s/c_p = \ln \left\{ Ma^2 \left[\frac{(\gamma_s + 1)}{(1 + \gamma_s Ma^2)} \right]^{(\gamma_s + 1)/\gamma_s} \right\}$, which is frequently plotted against the dimensionless entropy ($H = b/b^*$, with entropy at static temperature b^*), which yields the RAYLEIGH LINE.

Rayleigh line

[fluid dynamics, thermodynamics] Graphical representation of a flow condition with respect to adiabatic flow in a tube with constant cross-sectional area represented the enthalpy (S , respectively change: ΔS : $\Delta S = \Delta s/c_p = \ln \left\{ Ma^2 \left[\frac{(\gamma_s + 1)}{(1 + \gamma_s Ma^2)} \right]^{(\gamma_s + 1)/\gamma_s} \right\}$; see RAYLEIGH FLOW plotted against the dimensionless entropy ($H = b/b^*$, with entropy at static temperature b^*) (see Figure R.42).

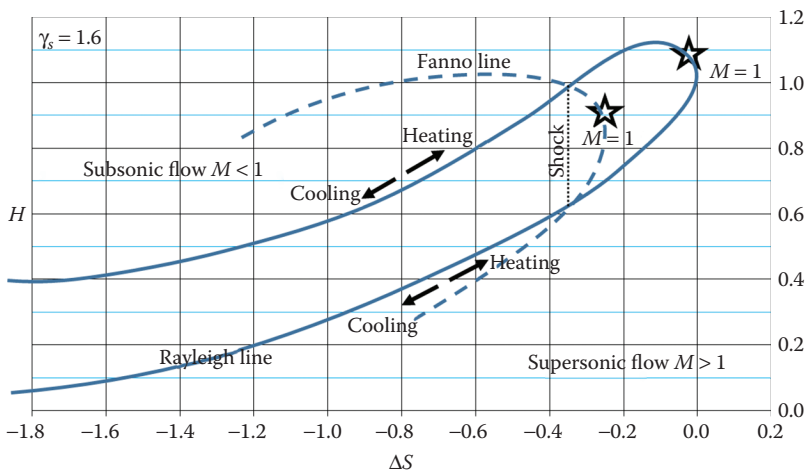


Figure R.42 Rayleigh line.

Rayleigh number ($Ra = L^3 \rho^2 g \alpha_{\text{exp}} \Delta T c_p / \eta \kappa = GrPr$)

[fluid dynamics, thermodynamics] Dimensionless number applying to convective and general HEAT TRANSFER, where L is the characteristic length (e.g., thickness of layer), ρ the density, g GRAVITATIONAL ACCELERATION, α_{exp} THERMAL EXPANSION coefficient, ΔT the temperature gradient across the phenomenon, c_p heat capacity, η the VISCOSITY, κ THERMAL CONDUCTIVITY, and Gr the GRASHOF NUMBER and Pr the PRANDTL NUMBER. The Rayleigh number can be used in BOUNDARY LAYER effects during surface heating and provide the thermal gradient.

Rayleigh scattering

[biomedical, general, nuclear] ELASTIC SCATTERING (compare to RAMAN SCATTERING) of LIGHT of a certain wavelength (λ) under interaction with objects smaller than the wavelength as described by English mathematician John William Strutt, also known as LORD RAYLEIGH (1842–1919) in 1871. The scattering CROSS SECTION ($\sigma_R(\lambda)$) is defined as $\sigma_R(\lambda) = (128\pi^5 \alpha_R^2 / 3\lambda^4) (6 + 3\delta/6 - 7\delta)$, with α describing the function to the index of refraction(n) as $\alpha_R = (n - 1)/2\pi N_0$, where N_0 is the PARTICLE density ("concentration") and δ the DEPOLARIZATION factor. The scattered light will be polarized (as can be observed by applying a POLARIZATION

filter to a CAMERA lens, or polaroid sunglasses) With respect to the angular distribution (θ) of scattered radiance L , at a DISTANCE ℓ from the scatterer this rewrites as $L = L_0 \left(\pi^4 \alpha_R^2 / 3 \lambda^4 \ell^2 \right) (1 + \cos^2 \theta)$. Rayleigh scattering provides an explanation to the sky looking blue, since beyond the ATMOSPHERE there is darkness. At great angular distance from the SUN the blue light is remaining from the solar spectrum, whereas closer to the incident ray of the Sun the entire spectrum scatters and provides a COLOR tending to white near the Sun. White clouds, on the other hand, are the result of MIE SCATTERING (see [Figure R.43](#)).



Figure R.43 Blue sky over Mont Michel in France due to Rayleigh scattering of white light emitted by the Sun.

Rayleigh screening

[biomedical, imaging, optics] Screening method for determination of molecular separation while applying the ULTRACENTRIFUGE principle. In this method TRANSILLUMINATION of the sample vial with SOLUTE sediment generates an INTERFERENCE FRINGE pattern. The separation of the fringes has a direct correlation with the concentration of molecular aggregate, which will correlate to the DISTANCE to the axis of rotation.

Rayleigh–Bénard flow

[fluid dynamics] Convection flow. Discrete convective turbulent flow cells occur in a horizontal layer of a FLUID heated from below. Named based on the contributions by the French physicist Henri Bénard (1874–1939) and LORD RAYLEIGH (1842–1919), defined in 1900.

Rayleigh–Gans theory

[computational, optics] SCATTERING approximation for a scattering medium that has an index of refraction close to unity ($n \approx 1$), which shifts the weight to zero scattering ANGLE. The Rayleigh–Gans scattering is described for the condition $\alpha_R = (n - 1)/2\pi N_0 \cong n^2 - 1/4\pi N_0$, see RAYLEIGH SCATTERING. Also known as RAYLEIGH–GANS SCATTERING.

Rayleigh–Gans–Debye scattering

[computational, optics] Transition SCATTERING regime for Rayleigh and Mie scattering under index of refraction of scattering compound close to one (1). Scattering theory based on the contributions from LORD RAYLEIGH (1842–1919), Richard Martin Gans (1880–1954), and PETER DEBYE (1884–1966) (see **RAYLEIGH–GANS THEORY**).

Rayleigh–Jeans equation

[atomic, nuclear, optics] RADIATION law describing the BLACK-BODY radiant power emitted per unit solid angle within a frequency range ($\Delta\nu$), in the limit $h\nu/kT \ll 1$: $P_{\text{BlackBody/unitSolidAngle}} = \left(2k_bT/\lambda^2\right)\Delta\nu$ where $\lambda = c/\nu$ is WAVELENGTH, ν the frequency, c the speed of LIGHT, k_b is the BOLTZMANN CONSTANT, T the TEMPERATURE (in Kelvin). This law was the result of the combined efforts of LORD RAYLEIGH (1842–1919) published in 1900 and Sir James Hopwood Jeans (1877–1946) published in 1905. The validity of the Rayleigh–Jeans is identified by the Rayleigh–Jeans limit which is defined as $\lambda \gg (hc/k_bT)$ beyond this point PLANCK'S LAW is approximately equal to the Rayleigh–Jeans law (also see **BLACK-BODY EMISSION**, **RAYLEIGH EMISSION LAW**, and **ULTRAVIOLET CATASTROPHE**).

Rayleigh–Sommerfeld diffraction

[acoustics] Diffraction theory approached in plane WAVE, in contrast to the SPHERICAL WAVE Huygens–Fresnel diffraction (near-field), modified by GUSTAV ROBERT KIRCHHOFF (1824–1887) as the Fresnel–Kirchhoff diffraction theory. Modifications by the German (Prussia) physicist and mathematician ARNOLD JOHANNES WILHELM SOMMERFELD (1868–1951) of the work by LORD RAYLEIGH (1842–1919) expressed with respect to the Fresnel–Kirchhoff approximation: $A(\vec{q}) = \int_S \kappa(\vec{r}, \vec{q}) [A(\vec{r})/|\vec{q} - \vec{r}|] e^{-ik|\vec{q} - \vec{r}|} dS$, where dS is a surface ELEMENT, $\vec{q}$ a location on the screen, $\vec{r}$ a location of the surface ELEMENT, $A(\vec{r})$ the real value of the complex field AMPLITUDE in location $\vec{r}$, respectively $\vec{q}$; with the coefficient: $\kappa_{\text{RS}} = \cos\alpha/i\lambda$, where λ the wavelength under angular DISPERSION α for the angular position of the surface element; compared to Kirchhoff's interpretation: $\kappa_{\text{RS}} = (1 - \cos\alpha)/2i\lambda$.

Rayleigh–Taylor instability

[astrophysics/astronomy, computational, energy, fluid dynamics, thermodynamics] As part of thermonuclear instabilities with a solar flame the flare propagation becomes unstable when the density of the fuel (ρ_{fuel}) becomes greater than the density of the ash (ρ_{ash}) as described in $\tau_{\text{decay}}^2 = k_g \Delta\rho / 2\rho_{\text{avg}}$, where τ_{decay} represents the DECAY rate of the combustion, g is the GRAVITATIONAL ACCELERATION on the STAR, $\Delta\rho = \rho_{\text{ash}} - \rho_{\text{fuel}}$ the gradient in density between fuel and ash, and ρ_{avg} the average density of the mixture.

R–C Circuits

[electronics, general] Electronic circuit composed of resistors (R) and capacitors (C).

Reabsorption

[biomedical, chemical] The process of lysis (enzymatic or osmotic process in reference to a cellular condition) and assimilation of a substance which is produced by a biological entity as the end result of the cellular breakdown which has been secreted. In biology this describes a process in the KIDNEY.

Reactance (χ_L)

[electronics, general] Electronic parameter pertaining to inductance: L (e.g., coil): $\chi_L = \omega L$, where $\omega = 2\pi\nu$ the ANGULAR VELOCITY and ν the frequency of the alternating current through the “coil,” that is, INDUCTOR.

Reactor

[nuclear] *See* NUCLEAR REACTOR.

Réaumur, René-Antoine Ferchault de (1683–1757)

[general, thermodynamics] Scientist from France who introduced the Réaumur temperature scale with respect to his research in METEOROLOGY. The Réaumur scale used the FREEZING point of water as the zero degree mark, but in contrast to his later scientific follower ANDERS CELSIUS (1701–1744) with the CELSIUS SCALE, set the second calibration point on the scale for the boiling point of water at 80° , also making his scale in segments of 8, “octogesimal.” The Réaumur temperature gauge had significant initial popularity, but was soon replaced by the Fahrenheit scale (by DANIEL GABRIEL FAHRENHEIT, 1686–1736) in the United Kingdom and the United States and the Celsius scale in the rest of the world and is now only of historic value (see [Figure R.44](#)).



Figure R.44 René Antoine Ferchault de Réaumur (1683–1757). (Courtesy of Galerie des naturalistes de J. Pizzetta, Ed. Hennuyer, 1893.)

Reciprocal space

[computational, condensed matter, imaging] Graphic representation using imaginary coordinates that are configured to represent vector orientation that coincide with the normal to the vector in the real space. Real space identifies the locations of atoms in a structural setting, whereas the reciprocal space represents the MAGNITUDE and direction of momentum of the wavevector for the LATTICE structure. In this setting the special DISTANCE between the imaginary coordinates represents the reciprocal of the real interplanar distance. The reciprocal lattice configuration that provides the outline to display the FOURIER TRANSFORM for the wavefunction within the original lattice structure (prevalent lattice configuration: Bravais). The general mode of operations defines the reciprocal lattice vector as the reciprocal of the real interplanar distance multiplied by 2π , placing it in Fourier space, with units radians per unit length; which yield the units of the WAVE vector ($k = 2\pi/\lambda$) used for spectroscopic analysis (cm^{-1}). The reciprocal lattice defines the slopes

and planes of the crystal planes in a lattice structure. The reciprocal lattice can be made “visible” through illumination of a real lattice by X-RAY imaging. Also referred to as Fourier space or k -SPACE (see Figure R.45).

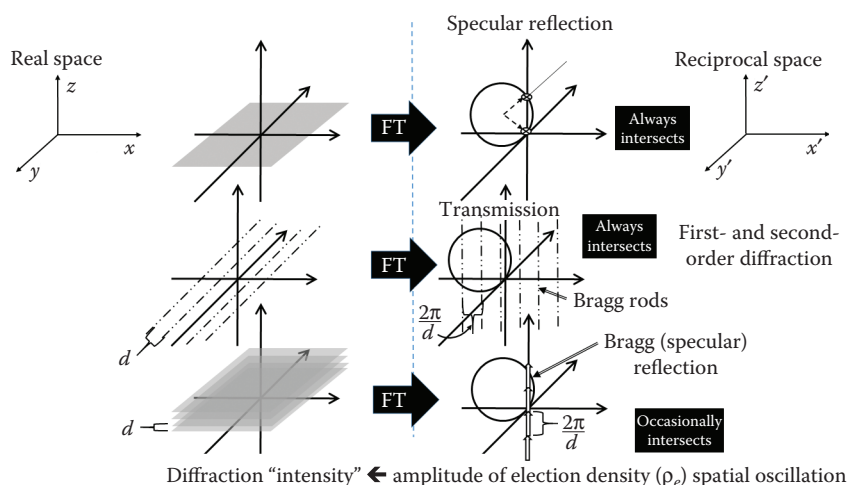


Figure R.45 Diagram representing the transition between real space and reciprocal space. Objects imaged in real space (left) are transformed to reciprocal space using Fourier transformation (FT). In reciprocal space (right-side) the representation may or may not have intersections with the Ewald sphere. The Ewald sphere defines the monochromatic radiation, illustrated as a two-dimensional project in the right-hand side (circle). The narrow-band (monochromatic) radiation is diffracted by the object in the direction that corresponds to the respective intersection of the Ewald sphere with the representation of the object in reciprocal space. For a planar interface there will be specular reflection. Specular reflection is represented by the intersection at the origin, which in turn corresponds to transmission. When assuming a line grating there will be additional intersections, each respectively corresponding to first-order and second-order diffraction within the object. The middle right diagram represents both orders in reflection, as well as in transmission. When imaging a set of planes, similar to what is, for instance, found in a crystal that is diffracting X-rays, the reciprocal space intersection may in actuality be absent. The definition of the orientation of the Ewald sphere is provided by the Bragg equation, which yields the intersect representing the reflections.

Reciprocity rule

R

[chemical] See **BUNSEN–ROScoe RULE**.

Recoil energy

[nuclear, quantum] Interaction of an energetic PARTICLE (elementary, alpha, etc.) with a NUCLEUS, transferring some or all of its momentum without changing the DEGREES OF FREEDOM of the nontranslational states. A specific recoil effect is induced during the emission of ALPHA DECAY. In contrast to resonant absorption of gamma RADIATION by the nucleus of atoms without loss to recoil described by Rudolf Mössbauer (1929–2011) in 1958, used in spectroscopic analysis pertaining to the nuclear ENERGY configuration. Rudolf Mössbauer along with Robert Hofstadter (1915–1990) received the Nobel Prize in Physics for their electron SCATTERING (and related alpha decay) in the nucleus with the recoil energy defining the nuclear energy configuration in 1961 (*also see* **MÖSSBAUER EFFECT**).

Rectifier

[electronics, general] Device used for conversion of ALTERNATING CURRENT (AC) ENERGY and rotating or three-phase current energy into direct current (DC) energy. This can be done in single-phase or multiphase modes. The mechanism of action can be either single-phase rectification or multiple-phase rectification.

The duty cycle of single-phase rectification is only 50%, whereas multiple phases can approach 100% duty cycle, depending on the number of phases involved and the level and participation of multiphase suppression.

Red

[electromagnetism] COLOR in the longer wavelength range for the visible ELECTROMAGNETIC SPECTRUM, considered to be one of the PRIMARY COLORS, in comparison to blue and green. The red color spectrum is at the extreme end of the visible spectrum, ranging from approximately 600 to 650 nm. On the shorter wavelengths LIGHT is yellow and on the longer wavelength side light is invisible INFRARED.

Red dwarf

[astrophysics/astronomy] Galactic STAR, classification that includes the definition for the approximate size of our SUN but much cooler, less than 4000 K (compared to 5800 K for our Sun). The mass of a red dwarf is less than 40% of the mass of our Sun, down to as little as 7.5% of the mass of our Sun. The emission of the red dwarf places it in the late K-spectral type or M-spectral type. The spectral type system for stars was devised by the Danish astronomer Ejnar Hertzsprung (1911–1967) in 1908, which was complemented by the astronomer from the United States HENRY NORRIS RUSSELL (1877–1957), which led to naming the classification the Hertzsprung–Russell diagrams. Red dwarfs presumably have no active nuclear reactions at the surface, the heat primarily emanates by convection. Due to the minimalistic nuclear reaction, remixing hydrogen and helium, these stars can live extremely long, hundreds of billions of years. In comparison, our Sun has an anticipated lifetime of 11 billion years before it reaches the WHITE DWARF stage, of which approximately 4.5 billion years has passed (no prospects for direct changes to the sun's luminosity and temperature at this point) (see [Figure R.46](#)).

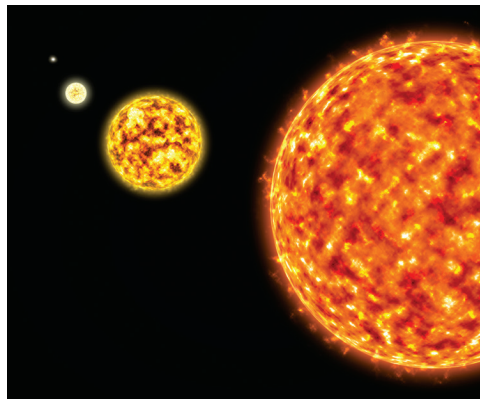


Figure R.46 Red dwarf representation; Stellar evolution of the Sun from yellow dwarf expand into huge red giant (left to right).

Red giant

[astronomy/astrophysics] Galactic star that passes through an evolutionary stage toward its demise (process of millions of years). The red giant evolves from a STAR that is low in mass, less than eight times the mass of our SUN. Due to hydrogen burn-up in the center the diameter of the star will grow to a diameter that is in the order of 100 times the size of our Sun, with associated lower ENERGY content, thus cooler and hence emitting at longer wavelength peak emission, creating the red glow. As it continues its growth process it becomes a red super giant with diameter in the order of 500 times that of our Sun, extending past the location of the earth's orbit. Our Sun is anticipated to eventually grow to a red giant with an anticipated increase in luminosity of 10,000 times the current radiance, while it cools to a temperature of 4,000 K with an approximate core temperature of 10^8 K. In the evolutionary process the red giant may progress to

become a WHITE DWARF once the hydrogen has been consumed with its final stage once the helium has been consumed, forming a black dwarf (see [Figure R.47](#)).

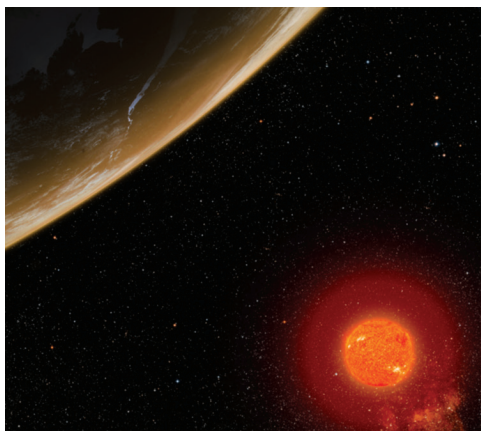


Figure R.47 Red giant representation in the vicinity of a planet.

Redox potential

[biomedical, chemical, energy] QUANTIFICATION of the potential to acquire electrons, forming a reduction process (see REDOX REACTION). The tendency that a chemical species will acquire electrons is measured in volts, the redox potential (see NERNST POTENTIAL).

Redox reaction

[biomedical, chemical, energy] Classification of a grouping of chemical reactions that have the OXIDATION reduction as the basis, transferring electrons between chemical species. The chemical interaction basis is either the reduction of electronic charge, either from negative ION to neutral or from neutral to a positive ion known as oxidation; respectively the gain of electrons is known as reduction generating a negatively charged ion (see [Figure R.48](#)).

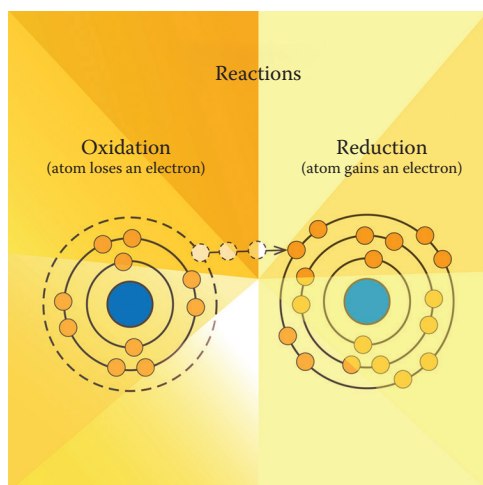


Figure R.48 Illustration comparing redox reaction with oxidation.

Redshift

[astrophysics/astronomy, computational] DOPPLER shift in spectral emission lines in the direction of longer wavelength due to the fact that the emission source is moving away from the observer, primarily observed on astronomic scale due to movement of stars. The spectral redshift was described in 1848 by HIPPOLYTE FIZEAU (1819–1896) for the first time. The emission lines are recognized transition lines for specific ELEMENTS, specifically hydrogen, helium, and certain metals. The redshift supports the “BIG BANG THEORY;” outlining the continual EXPANSION of the UNIVERSE (*also see* DOPPLER EFFECT) (see Figure R.49).

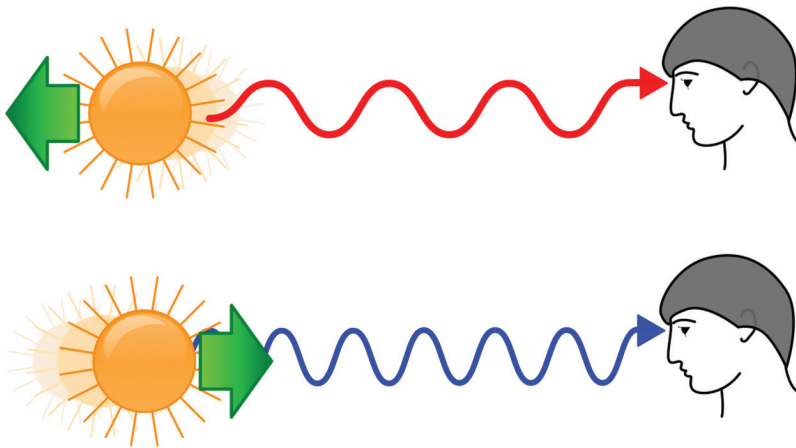


Figure R.49 Redshift diagram on top for a emitting source moving away with respect to the location of the observer. Doppler shift resulting from moving source. (Courtesy of Aleš Tošovský, Czech Republic.)

Reduced mass

[general] Mass measured when an object placed on a scale is submerged in water. This equates to the mass of the object in water from the mass of the object in AIR: $m_r = m - m_w$.

Reflectance

[atomic, general, optics] Image formed by reflection (see Figure R.50).

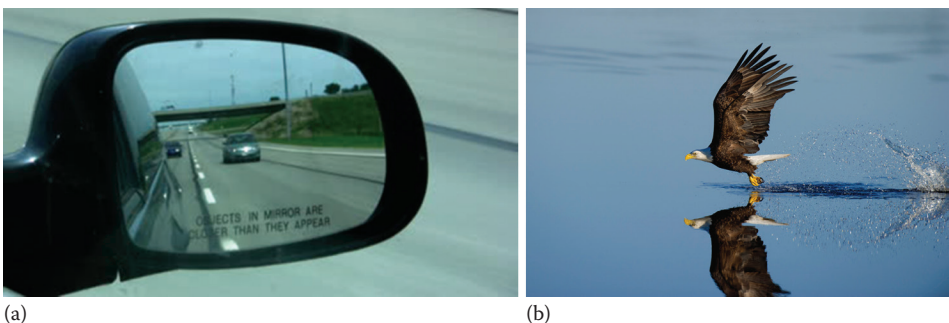


Figure R.50 (a) Object may be closer than they appear in the convex mirror and (b) reflection of a bald eagle in flight reflected by the undisturbed surface of the water, where the eagle broke the surface tension to capture a fish that was observed from the sky accounting for the refraction with respect to the underwater location of the fish as observed from air. (Courtesy of Ray Hennessy, <http://www.rayhennessy.com>.)

Reflecting telescope

[general] TELESCOPE using curved mirrors for rays forming and associated magnification in addition to lenses (see [Figure R.51](#)).

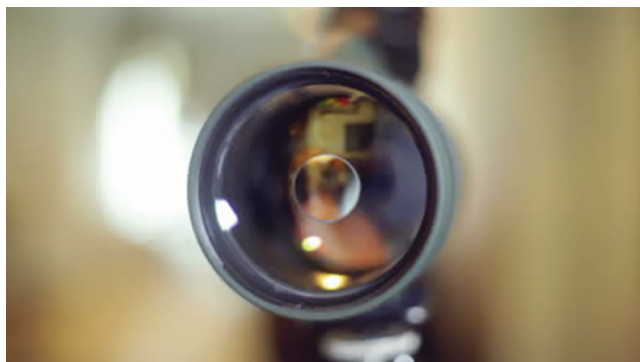


Figure R.51 Reflection telescope design.

Reflection

[atomic, general, nuclear, optics] Redirection of ENERGY wave stream that conforms to PARTICLE characteristics, resembling a ball bouncing of a WALL. The path of the WAVE propagation will form an ANGLE with an interface, where the path equates to the rectilinear propagation of a PROJECTILE. The angle of incidence of LIGHT measured with respect to the normal to the surface equals the angle of reflection. Electromagnetic RADIATION is redirected at a boundary that has different optical density from the adjacent medium, pertaining to the DIELECTRIC properties: permittivity and permeability. ACOUSTIC WAVES reflect from a boundary with different density, as do mechanical waves (i.e., water waves). Also described as specular or diffuse reflectance. Specular reflectance creates a real or virtual IMAGE that generally has the outline of the object reversed in the plane of reflection and remains crisp and clearly visible, whereas diffuse reflectance mixes the reflected rays in random directions due to the interaction from a surface or interface that is not perfectly smooth; hence the outline of the image does no longer match the object. Reflection also applies to waves of electrons, using the DE BROGLIE WAVELENGTH as the wave phenomenon next to the particle characteristics, both applied to electron microscopy imaging (see [Figure R.52](#)).

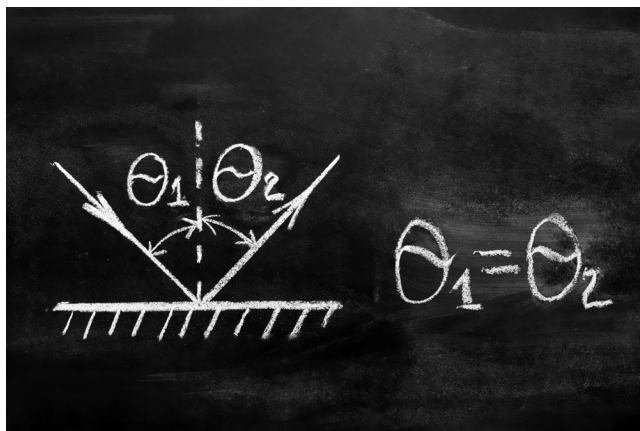


Figure R.52 Principle of reflection: equal angles with respect to normal to the surface.

Refraction

[acoustics, general, nuclear, optics] Redirection of wave of ENERGY at an interface with a change in direction that has a diminished vector component in the direction of the incident ray; the ray proceeds in the second medium with a direction that is a function of the density and obeys the equivalent of SNELL'S LAW for all forms of energy. In OPTICS the refraction is coupled to the characteristics of the medium identified as the index of refraction; linking the velocity of propagation to the definition of the medium. Refraction also applies to waves of electrons, using the DE BROGLIE WAVELENGTH as the WAVE phenomenon with respect to electron microscopy imaging (see Figure R.53).

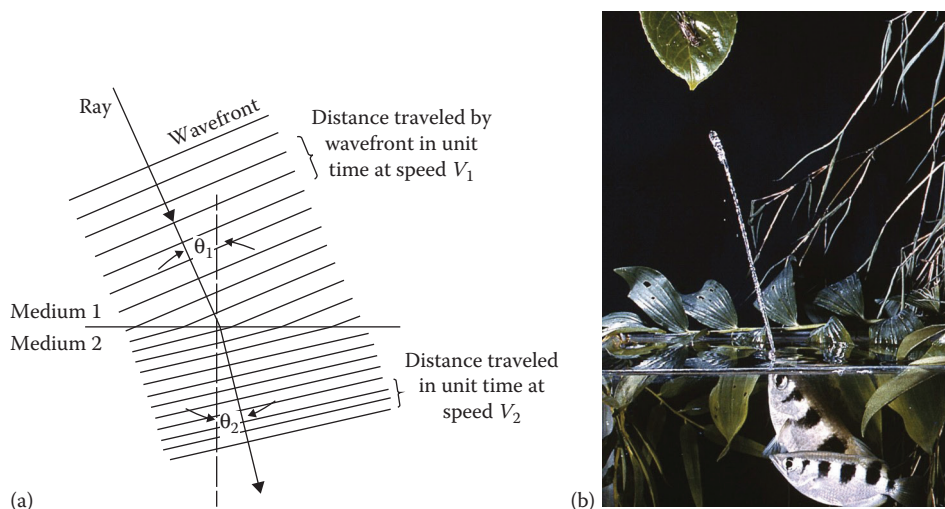


Figure R.53 (a) Principle of refraction. (b) Archerfish “spitting” at insect above the waterline, compensating for the refraction, hitting the insect and capturing it for consumption. Apparently the archerfish is able to modulate the jet-phase flow velocity (dispersion, frequency modulation, etc.) to shape the jet providing higher efficiency in disabling the prey. Note that the jet is a wave phenomenon.

Refraction, index of (n)

[general, optics] See INDEX OF REFRACTION.

Refraction, law of

[general] See SNELL'S LAW.

Refrigeration cycle

[thermodynamics] Compression cycle leading to a reduction in temperature. This principle applies to refrigeration: refrigerator and air-conditioning (*also see* RANKINE CYCLE).

Reines, Frederick (1918–1998)

[astrophysics/astronomy, general, nuclear] Physicist from the United States. Discoverer of the NEUTRINO and antineutrino, in collaboration with the American physicist Clyde Lorrain Cowan (1919–1974) in 1956. The equivalent mass of the antineutrino has been derived to be less than $27 \text{ eV}/c^2$, with c the speed of LIGHT in 1986. Additional efforts of Frederick Reines were in the description and the workings of SUPERNOVA stars.

Reines received the Nobel Prize in Physics with Martin Lewis Perl (1927–) in 1995 for the discovery of the TAU LEPTON (see [Figure R.54](#)).



Figure R.54 Frederick Reines (1918–1998).

Relative density

[general] The nondimensional expression for the density of an object expressed as the ratio of the mass-in-air to the difference of the mass-in-air and the mass-under-water: relative density = $\rho/\rho_w = (m/V)/(m_w/V) = m/m_w = m/(m - m_r)$ = specific gravity, which is equivalent to the specific gravity. The quantity is the density while the subscripts respectively represent the mass of displaced FLUID and REDUCED MASS (or APPARENT MASS). The concept was first introduced by AL-BIRUNI (973–1048) in approximately 1025, while he was a philosopher and scientist in the Persian Empire.

Relative humidity (RH)

[thermodynamics] Measure of the ratio of water VAPOR content, measured as partial pressure (P_i), in a volume of a mixture of gases at a specific temperature with respect to the partial pressure of saturated water vapor in equilibrium with a LIQUID water bath, where saturated water vapor defines 100% percent. $RH = (\text{actual vapor density at a certain temperature} / \text{saturated vapor density at the same temperature}) \times 100\% = (P_{H_2O,T} / P_{SatH_2O,T}) \times 100\%$.

Relative permeability

[fluid dynamics, thermodynamics] In a cyclic thermodynamic process, the FLUID saturation will reveal HYSTERESIS with respect to PHASE transitions between the various phases in the mixture, specifically under conditions of a porous medium. The absolute permeability of a porous medium defines the ability to transmit fluids. The effective permeability relates the permeability of a particular phase in the context to other phases present. The relative permeability is the ratio of the effective permeability to the baseline permeability of the porous medium (e.g., rock). Permeability has its relevance in fracturing (fracking), where there is a presence of water, OIL, and other fluid media (including gases) in porous and semiporous rock or rock that will need to be made more permeable.

Relative permittivity

[thermodynamics] The DIELECTRIC permittivity can generally be considered as independent of the external MAGNETIC and electric fields provided the respective magnitudes are low. The permittivity can be described as dependent on both temperature and density, expressed relative to the permittivity of VACUUM as follows: $\epsilon = \epsilon_0 + (\rho/M)[\alpha + (d^2/3kT)]$, where k is the Boltzmann constant, d the ELECTRIC DIPOLE MOMENT of the respective molecules in the volume, ρ the density, M the MOLECULAR WEIGHT, and α the molecular POLARIZATION.

Relaxation time

[biomedical, computational, mechanics, nuclear, solid-state] Time period in which a phenomenon decreases to a value that is a fraction e^{-1} times the initial value. This may relate to, for instance, temperature effects, SPIN (ELECTRON SPIN under excited conditions), MAGNETIC RESONANCE (ref. MRI), electronic circuit current fluctuations (CAPACITOR discharge), mechanical (stress/strain) as well as NUCLEON and electron transitions, however, not limited to these alone.

Renaldini, Carlo {Rinaldini} (1615–1698)

[general] Engineer and nobleman from Italy who was one of the first scientists to suggest the use of the PHASE transitions of water as calibration points for a temperature scale (i.e., THERMOMETER) and provided experimental proof of the concepts in 1654. Note that the originators of several temperature scales, such as ANDERS CELSIUS (1701–1744), DANIEL GABRIEL FAHRENHEIT (1686–1736), RENÉ ANTOINE FERCHAULT DE RÉAUMUR (1683–1757), and WILLIAM THOMSON, 1ST BARON KELVIN (1824–1907) all lived after Renaldini (see [Figure R.55](#)).



Figure R.55 Carlo Renaldini (1615–1698).

Rényi, Alfréd (1921–1970)

[imaging, theoretical, thermodynamics] Mathematician and physicist from Hungary. Alfréd Rényi is known for his contributions to PROBABILITY theory, graph theory, and combinatorics as well as number theory. His contributions to the stochastic nature of thermodynamic process is expressed by the RÉNYI ENTROPY (see Figure R.56).



Figure R.56 Alfréd Rényi (1921–1970). (Courtesy of Hungarian Foreign Ministry, Hungary.)

Rényi entropy

[computational, imaging, theoretical, thermodynamics] Theoretical analysis of the additive effects of independent events. Practically, it is the derivative of the (Gibbs) free energy (G) with respect to the functional parameter for the system, introduced by ALFRÉD RÉNYI (1921–1970). The entropy is defined by this parameter; assume the spatial factor “ q ,” describing the state of an “event,” with respect to the TEMPERATURE (T) of the system, described as $(dG/d(1/q))_T$. Rényi’s approach uses the stochastic influences and improves on the Shannon entropy model, which is a linear approximation on averaging. The entropy approach incorporates an exponential function to describe the PROBABILITY (p) aspect of achieving certain states (j) expressed as the “information” (information potential ($I(p)$)) in under certain conditions for a multidimensional system consisting of a range of independent events: $I(p) = \mathcal{G}^{-1} \{ \sum_{j=1}^N p_j \mathcal{G}(I_j(p)) \}$, where $\mathcal{G}$ provides the format of interaction for independent events, which is $\mathcal{G} = e^{*q}$ for Shannon’s model, and in the model by Rényi this is replaced by $\mathcal{G} = e^{*-2(1-\alpha)q}$, with $I_j(p)$ the information potential estimator for the respective states (j), e^* a coefficient for the system, q the localization factor, α a scaling parameter, and I -norm designated as the NORMALIZATION of the maximum likelihood distribution. The Rényi entropy reduces to $I_\alpha(p) = [1/(1-\alpha)] \log(\sum_{j=1}^N p_j^\alpha)$, defining a family (plural) of information measures (Rényi entropies).

Reproduction factor

[atomic, nuclear] See MULTIPLICATION FACTOR.

Reserve volume (RV)

[biomedical, fluid dynamics] Classification of lung volumes, consisting of INSPIRATORY RESERVE VOLUME and expiratory reserve volume. The vital capacity of the lung is the sum of the inspiratory reserve volume, the expiratory reserve volume, and the TIDAL VOLUME; where the combination inspiratory reserve volume and

tidal volume constitutes the **INSPIRATORY CAPACITY**. The expired reserve volume refers to the lung volume that can be forcefully exhaled what is remaining after normal expiration (see [Figure R.57](#)).

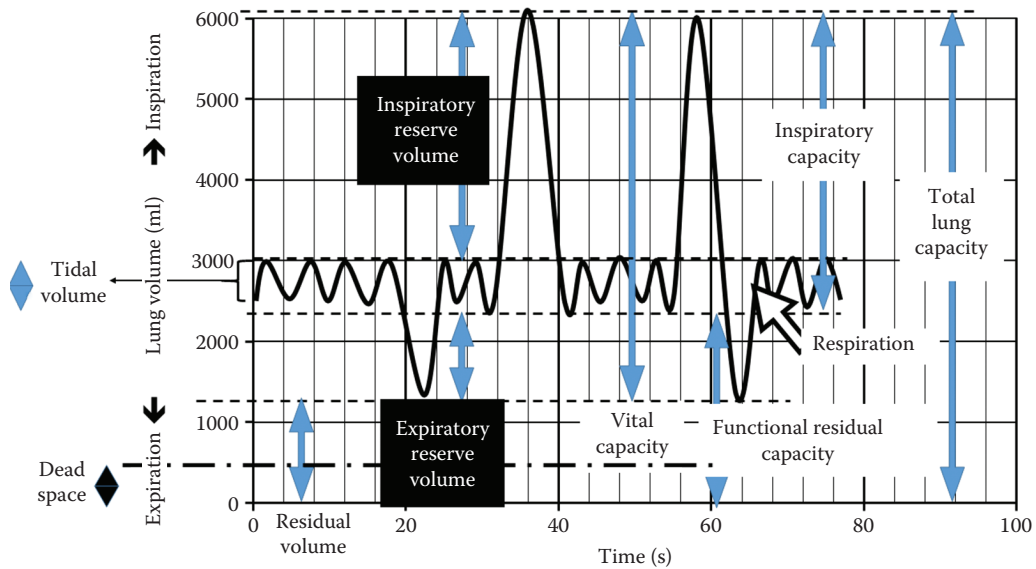


Figure R.57 Diagram of respiration and the two kinds of reserve volume involved.

Residual nucleus

[atomic, nuclear] The residue of a nuclear disintegration from the base atomic structure, where a different kind of **PARTICLE** is emitted resulting from an incident particle interaction, or more than one particle is emitted. The process is referred to as the reaction of transmutation, indicating that the **NUCLEUS** is transmuted into another nuclear species.

Residual volume

[biomedical, fluid dynamics] The lingering quantity of **GAS** remaining in the lungs after exhalation to the maximum effort. Residual volume and other **TIDAL BREATHING** parameters can be measured with a spirometer. The volume of **AIR** occupied in the lung remaining after normal expiration is called the functional residual capacity, which constitutes the expired reserve volume and the residual volume (see **RESPIRATION** and **PHYSIOLOGIC DEAD SPACE**).

Residuals

[computational, fluid dynamics] Method of solving for the Navier–Stokes equation using “weighted residuals.” The weighted residuals are the statistical distributions with regard to the error in the order of termination for the polynomial development of the **SOLUTION** function.

Resistance

[biomedical, electronics, fluid dynamics, mechanics] Reactance to a phenomenon, diminishing the **MAGNITUDE** of a physical parameter that defines the system. In **ELECTRONICS** either the current or the voltage is reduced due to resistance, while flow in general is reduced as a result of resistance, specifically pertaining to

fluid-dynamic conditions. Under mechanical translation, the resistance is embodied by frictional forces or general hindrances such as unevenness in the surface or a wedge between two surfaces. Under biomedical conditions the resistance is also offered through the presence of an **ANTAGONIST** muscle with respect to the intended **MOTION**. In electronics the electrical resistance follows from **OHM's LAW**, relating the voltage drop (V) over a resistance (R) due to a **CURRENT** (I) as $V = IR$.

Resistor

[electronics, general] Physical device in electronic circuit that obeys **OHM's LAW** and provides a voltage drop between the two poles when a current is applied (*see* **RESISTANCE**) (*see* [Figure R.58](#)).

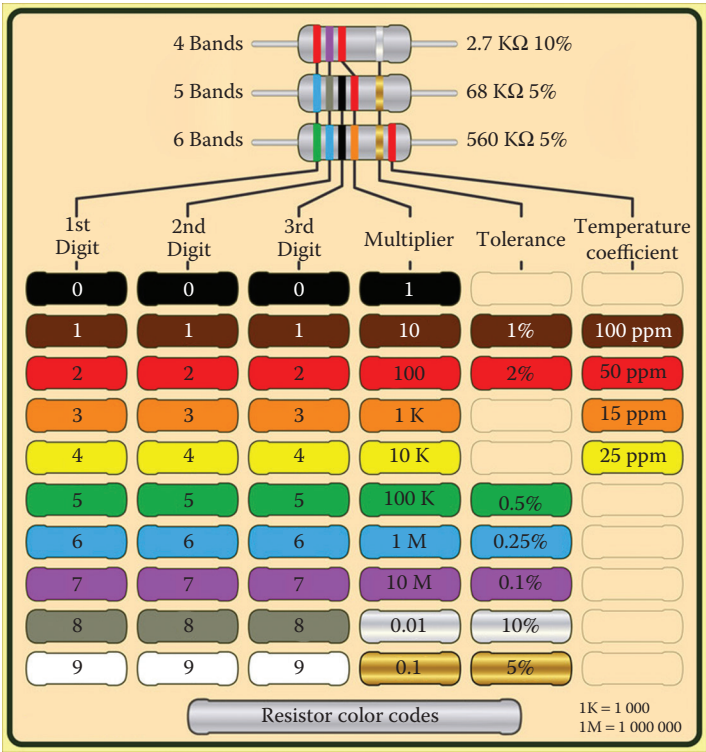


Figure R.58 Electrical resistor in electronic circuit and color code used to identify the ohmic values for conventional resistors.

Resolution

[general] Due to the **DISTANCE** factor between the object under observation and the viewing device resolution is expressed by the angular limit of the separation resolution between two points on an object. The resolution is provided by the **Raleigh criterion**, or alternatively the **ABBE CONDITION** (*also see* **AIRY DISK**).

Resolving power

[general, nuclear] The ability to distinguish between two events or two locations on an object, respectively identify the minimum separation between two objects. Newspaper print in particular takes advantage of

this phenomenon, relying on an observation DISTANCE that will blend the half-tone dots in the printed images into a grayscale, or COLOR, smooth visual interpretation (see [Figure R.59](#)).

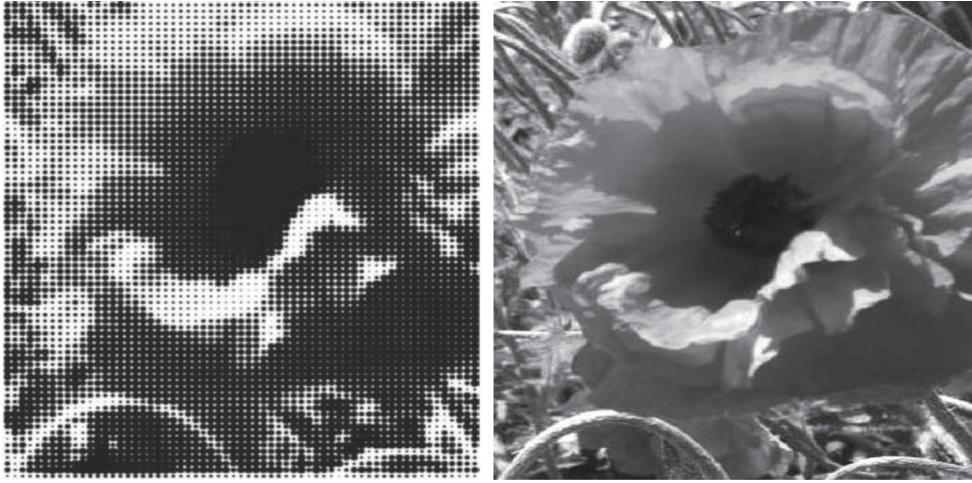


Figure R.59 Resolving power.

Resonance

[acoustics, atomic, computational, electromagnetism, fluid dynamics, general, mechanics, quantum]

Three types of resonant systems can be identified: (1) mechanical (e.g., ACOUSTICS), (2) electromagnetic, and (3) electronic. A mechanical system under temporal fluctuating external force will come to resonance when the driving frequency matches the mechanical boundary conditions of the system, either dimensions in multiples of half (e.g., closed box, solid stick, closet with door closed, etc.) or quarter wavelengths (e.g., open box, flute). Alternatively, an electronic system will come to resonance when the applied external alternating electrical potential matches the circuit conditions for the characteristic frequency of the system, for instance, the free-running frequency: $\nu = 1/2\pi\sqrt{LC}$ for an undamped CAPACITOR (C) and INDUCTOR (L) circuit, respectively, adding DAMPING by including a RESISTANCE in the circuit. In electronic circuits, there are three resonant configurations: series, parallel, and two branch. A resonant electromagnetic system refers to a PHOTON, which by definition has an infinite lifetime (*also see* OSCILLATION, MASS-SPRING SYSTEM, FREQUENCY, RESONANT, and Q-FACTOR [quality factor]) (see [Figure R.60](#)).

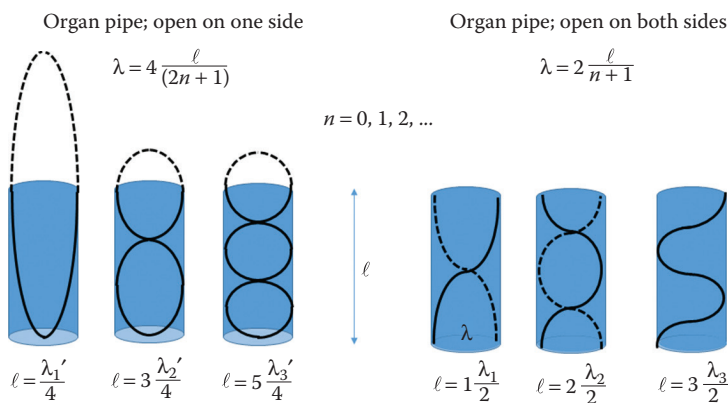


Figure R.60 Resonance.

Resonance absorption

[atomic] Electromagnetic absorption that matches the wavefunction of an atomic orbit, hence in **RESONANCE** with the electron **ENERGY** for excitation to the next energy level. A particular example of resonance absorption are the Lyman lines of hydrogen in the far **ULTRAVIOLET**.

Resonance frequency

[acoustics, biomedical, imaging] Frequency of oscillatory **ENERGY** field that matches the autonomic frequency of one of the parameters that define a system. In **ACOUSTICS** the frequency of a structure is directly dependent on the dimensions of the device, where at least one of the dimensions will need to match a quarter or a half wavelength multiplied by an integer, depending on whether the ends are loose (free to move independently) or fixed, respectively. In magnetic resonance imaging (MRI and NMR, respectively) the **RADIO** frequency perturbation of the **MAGNETIC FIELD** will need to match a oscillatory frequency of the **NUCLEAR MAGNETIC MOMENT** spin, usually in the radio frequency range. A structure exited at the resonance frequency and continuously stimulated will acquire a significant amount of energy which may eventually result in failure of the structure. Microwave ovens (i.e., magnetron) apply **MICRO-WAVE** electromagnetic **RADIATION** to bring water to its resonant **VIBRATION** relying on **DIPOLE** interaction, hence raising the local temperature and thus heating the food (i.e., water) (*also see* **FREQUENCY, RESONANT**) (see [Figure R.61](#)).



Figure R.61 Bell ringing at its resonance frequencies. Due to the shape of the bell there are a multitude of vibrational characteristic dimensions, which provide the spectrum of the sound of the bell, the "color" of the sound. Vibrating string with frequency determined by the tension and the length of the string as defined by "father" Marin Mersenne (1588–1648), see "**MERSENNE**."

Resonance potential

[atomic] The **ENERGY** required to raise an electron from its **GROUND STATE** to an excited state with certain associated freedom of movement, hence dissociating the **ATOM**. On an atomic level this requires traversing a potential energy **BARRIER**, the resonance potential. This concept was validated by **JAMES FRANCK** (1882–1964) and **HEINRICH HERTZ** (1857–1894) in 1913, who verified the dissociation energy of mercury vapor under 4.9 eV applied energy, the resonance potential for mercury, a single atom **GAS**. Mercury has an **IONIZATION POTENTIAL** of 10.4 eV, however at the resonance potential the electrons are in direct interaction with the **CATHODE** ray electrons in the **VACUUM** tube. The **RESONANCE** of the excited

electrons and the ballistic electrons results in a direct decrease in the current in the vacuum tube (*also see IONIZATION*) (see [Figure R.62](#)).

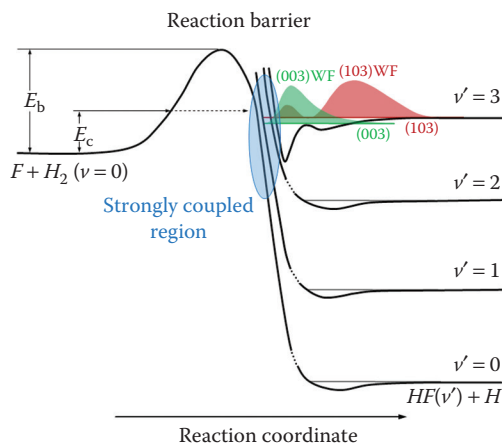


Figure R.62 Resonance potential, graphical representation of the Feshbach resonances in the $F + H_2 \rightarrow HF + H$ chemical reaction. (Courtesy of Dalian Institute of Chemical Physics, Chinese Academy of Sciences; Group 1102: Laboratory of Reaction Dynamics; Dalian, Liaoning, China.)

Resonance reactions

[nuclear] In the process of nuclear interaction resulting from PROJECTILE particles there are opportunities for population of EXCITED STATES by PARTICLE capture (e.g., NEUTRON or charged particle), where RESONANCE is induced supporting a constant reaction rate resulting from capture at the appropriate ENERGY (see [Figure R.63](#)).

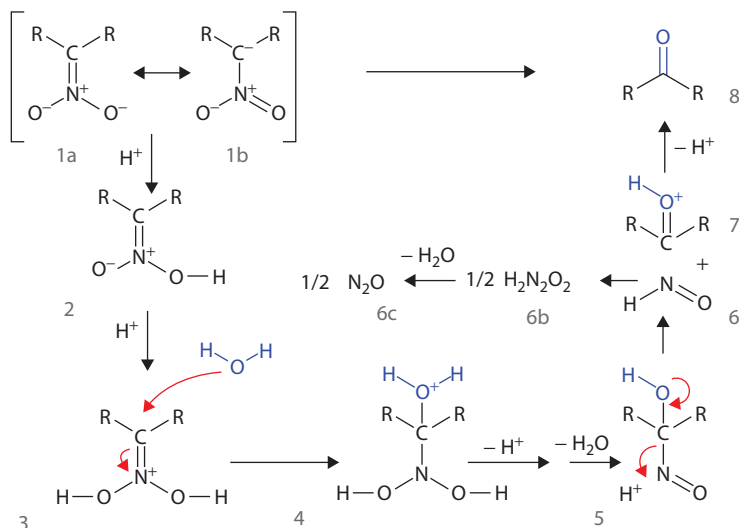


Figure R.63 Resonance reaction: chemical reaction with recursive energy exchanges.

Resonance states

[atomic, condensed matter] Peak in the ENERGY density for subatomic particle interaction with nuclides (e.g., BARYON, upsilons mesons) resulting in an excited state that is a function of the CROSS SECTION of the PARTICLE interaction providing the RESONANCE peak: $\Gamma_r = \hbar/\tau$, where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT and τ is the lifetime of the excited state of the particle or the lifetime of the particle itself. The resonance state is an indication of the energetic width of the excited state, indicating the PROBABILITY of interaction.

Respiration

[biomedical] The process of oxygen intake by means of exchanging AIR by exhaling low SATURATION PRESSURE oxygenated fluids and inhaling high saturation pressure fluids. In the same process the carbon dioxide exchange is from high to low due to CARBOHYDRATE oxidation in the biological medium producing carbon dioxide as a metabolic waste product. The air intake/outflow is generally comprised of the following constituents and relative values with variable water VAPOR PRESSURE depending on RELATIVE HUMIDITY. Intake 20% O₂ – 7% N₂ – 60% CO₂; outflow 16% O₂ – 7% N₂ – 64% CO₂. Respiration efficiency is directly correlated to the exchange in volumes and the total volume of the respiration device (i.e., lung) (see RESIDUAL VOLUME, TOTAL LUNG VOLUME, EXPIRED VOLUME, INHALED VOLUME, and VITAL CAPACITY). The oxygen—carbon dioxide exchange takes place in the Alveoli of the lung under a blood–gas BARRIER (see ALVEOLI, HEMOGLOBIN, and LUNG) (see Figure R.64).

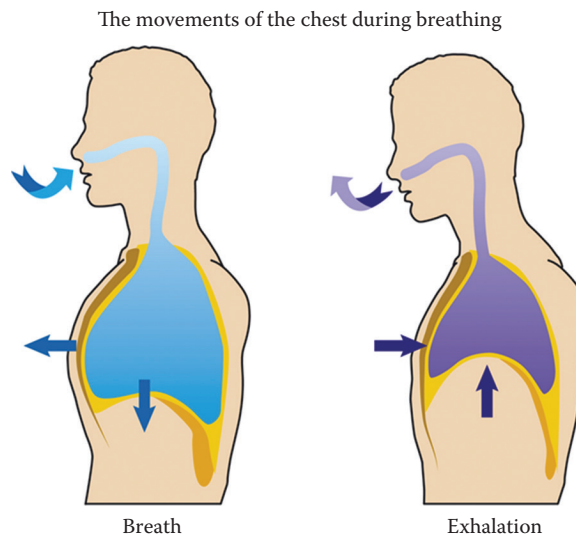


Figure R.64 Human respiration.

Rest energy (E_0)

[general, relativistic] The ENERGY of a system with mass m in a particular state, consisting of momentum and velocity under relativistic conditions has a rest energy $E_0 = mc^2$, where $c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8 \text{ m/s}$ is the speed of LIGHT in VACUUM.

Rest mass

[atomic, nuclear] Relativistic mass for a system containing a mass m_0 that consists of movement with velocity v with respect to an observer in a reference frame, defined as $m_r = m_0 / \sqrt{1 - (v^2/c^2)}$, where $c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s is the speed of LIGHT in VACUUM.

Resting potential

[biophysics, chemical, electromagnetism, energy] See MEMBRANE POTENTIAL.

Retina

[biomedical, chemical, optics] Cellular layer on the inside WALL of the EYE on the opposite side with respect to the LENS. The retina has two types of CELL for the detection of light: RODS and CONES. The retina of the HUMAN EYE contains approximately 120 to 130 million rods and 6.5 to 7 million cones (the cones are concentrated primarily in the FOVEA of the eye). The rod cells are primarily geared to the detection of radiance, and provide black and white (grayscale) vision. The cones are diversified in three specific sensitive wavelength ranges, respectively RED, green, and blue with a broad sensitive range, largely overlapping. The cones of the eye are sensitive approximately from 330 to 660 nm, which varies with AGE and depending on the applied radiance from the source. The retina has a pigment layer that can reduce the MAGNITUDE of light that will be collected at the rods or cones. The LIGHT incident on the lens of the eye will traverse the VITREOUS HUMOR before reaching the retina. At the retina the pigment layer is encountered first; next the light traverses the choroid respectively (vascular layer), before the light is reflected from the sclera (the white part of the eye), after which the light returns back through the pigmented layer before detection is possible in the rods and cones. The macula provides high-resolution COLOR and black and white vision in a spot of approximately 5.5 mm diameter (depending on the size of the eye), with the central fovea (diameter of approximately 1.5 mm) which contains only cones. The rods are spread out over a large surface and yield dark vision as well as peripheral vision. (also see EYE) (see Figure R.65).

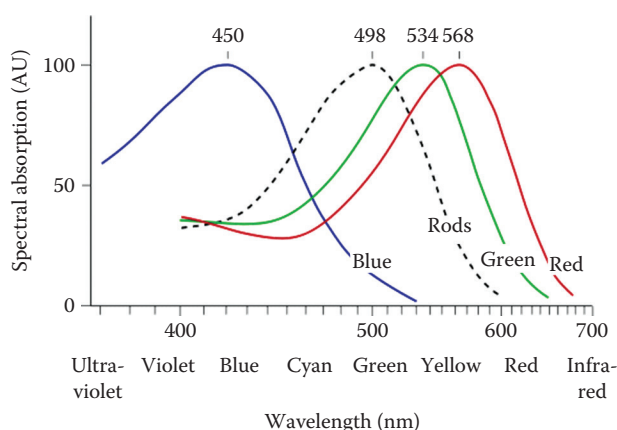


Figure R.65 Retina. Including a representation of the area of the retina where the optic nerve leads off to the rain, with nerve fibers instead of rods and cones leaving a proverbial and true "blind spot." Illustration of the three color vision cone sensitivity yielding ultimate white color by signal analysis integration.

Reverberation

[acoustics, fluid dynamics, general] The compounded cumulative effect of multiple reflections of **SOUND** waves within an enclosure. The characteristics of reverberation created in an enclosed environment are affected by the materials of which the enclosure is constructed as well as the material construction (geometry and materials) of any object and partitions in the enclosure and the size and shape of the enclosure. Materials can both selectively dampen a spectral profile and reflect (see [Figure R.66](#)).



Figure R.66 Reverberation: cymbal, triangle, and drum skin vibrating under percussion by hand.

Reverse osmosis

[biomedical, chemical, general] Water purification process that uses a **SEMIPERMEABLE MEMBRANE** to filter out potentially harmful, and generally unwanted constituents and ingredients from unknown source or unreliable quality water supply. Osmosis itself is the process of influencing the flow of a **SOLUTE**, primarily water, to pass across a (semipermeable) membrane between two different concentration solutions, with an inherent partial pressure gradient, forcing the **SOLVENT** flow to further dilute the higher solute concentration on one side of the membrane. One specific application is the removal of **SALT** from seawater (desalinization) for drinking purposes. Reverse osmosis applies external pressure, thus modifying the chemical potential, which will force the solvent flow to counterbalance the **OSMOTIC PRESSURE** resulting from the solutes. The mechanism of action thus retains the solute on the pressurized side of the membrane and the solvent will pass through (see [Figure R.67](#)).

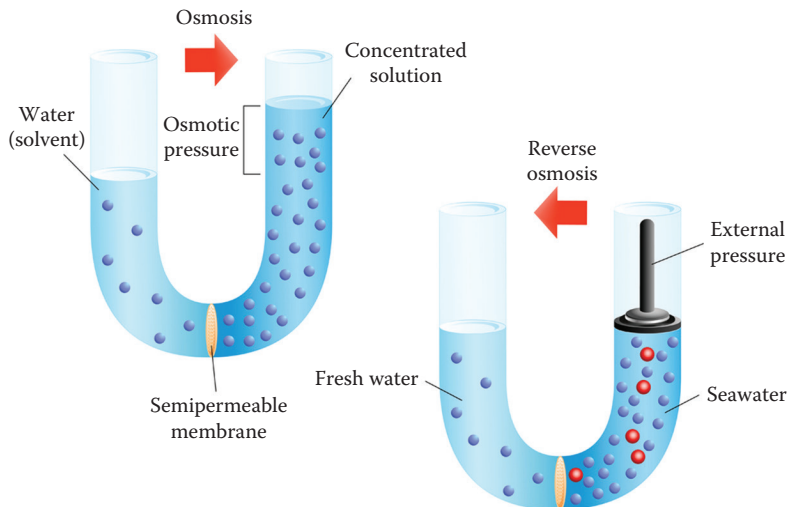


Figure R.67 Reverse osmosis process, as well as used in desalinization.

Reverse-biased diode

[electronics, general] Semiconductor **DIODE** that is placed in a circuit in conductive direction that is opposite the favored conduction. The general definition of the diode is an electrical device that allows current to move through it in one direction preferred over the opposite direction (*see* **DIODE** and **pn-JUNCTION**; *also see* **ZENER DIODE**).

Reynolds, Osborne (1842–1912)

[biomedical, fluid dynamics, thermodynamics] Scientist from Ireland. Osborne Reynolds is known for his contributions to scaling of flow and the definition of boundary conditions in a flow system. Specific contributions were in the understanding and conditions affecting the onset and persistence of turbulent flow. Additional work by Reynolds was in the **HEAT TRANSFER** between solids and fluids. The work of Osborne Reynolds has provided the Reynolds numbers for flow and for heat transfer and helped in the design of objects to influence the aerodynamic aspects, such as the dimples on the **GOLF BALL**. The dimples in the surface of the golf ball enhances **TURBULENCE**. This turbulence narrows the **WAKE** (concurrently reduces the flow **RESISTANCE**) and will result in an increase of the trajectory **DISTANCE** of the ball by up to 50%. The dimples in the golf ball result in a specific **REYNOLDS NUMBER** for flow, which provides the theoretical conditions for minimal velocity to induce turbulence. On an anecdotal note, Reynolds described the phenomenon of wet sand drying out when one steps in the sand locally. Reynolds recognized that lapping waves bring sand to an optimal packing. The granular packing yields sand grains as close together as they can get. Under the influence of external compaction resulting from the footprint more empty space is created, allowing the water to flow into the sand mass, temporally draining the water from the surface (*see* [Figure R.68](#)).

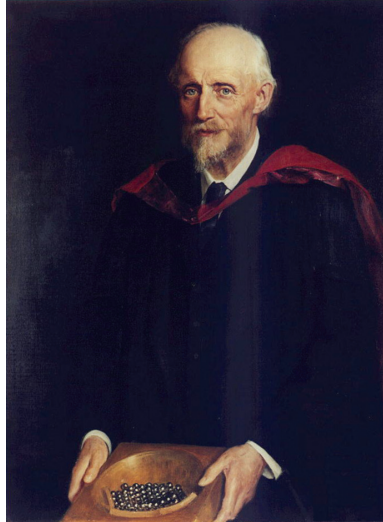


Figure R.68 Osborne Reynolds (1842–1912) in 1903, painted by John Collier.

Reynolds experiment

[fluid dynamics] Experimental design to illustrate **LAMINAR FLOW**, turbulent flow, and the progression (transitional flow) from laminar to fully turbulent flow.

Reynolds number

[biomedical, fluid dynamics] $Re = (D \times \rho \times v) / (\eta \times g)$, dimensionless number portraying the ratio of the net inertial force to the viscous force, where η is the VISCOSITY, D the core length of the phenomenon (i.e., length of the tube of object, e.g., automobile, train, plain, etc.), ρ the DENSITY (also SPECIFIC WEIGHT) of the FLUID, v the average relative flow velocity, and g is the GRAVITATION due to acceleration.

Reynolds number, magnetic ($Re_m = \mu \sigma v_{fl} L$)

[fluid dynamics, geophysics] Dimensionless number applying to magnetic field–fluid DYNAMICS describing the interaction of MAGNETIC FIELD and FLUID flow (e.g., magma), where μ is the DIELECTRIC permeability, σ the electrical conductivity, L the characteristic length, and v_{fl} the FLUID FLOW VELOCITY. The MAGNETIC REYNOLDS NUMBER can indicate when MAGNETIC convection over the RELAXATION TIME is small with respect to the size of the phenomenon. For large magnetic Reynolds number ($Re_m \gg 1$), the electromagnetic (i.e., the electric current and magnetic field) response can be 180° , or π rad out of PHASE with the flow, resulting in abrupt changes in the local MAGNETIC FIELD with associated ENERGY surges and shock waves.

Reynolds stress

[fluid dynamics] Terms in the Navier–Stokes equation related to FLUID shearing stresses, as expressed by the term $-u_i u_j$ for the velocity components with respect to all the DEGREES OF FREEDOM in $U_j (\partial u_i / \partial x_j) = (\partial P / \partial x_i) - (\partial / \partial x_j) (u_i u_j) + \eta_{kin} \nabla^2 U_i$, where u_i is the perturbation and u_i the mean MAGNITUDE of the i component of the velocity profile in direction x_i , $\nabla^2 = \sum (d^2 / dx_i^2)$ the Laplace operator, η_{kin} the KINEMATIC VISCOSITY, and P the mean pressure.

Rheobase

[biomedical, chemical, electronics] See RHEOBASIC CURRENT.

Rheobasic current

[biomedical, chemical, electronics] The smallest ION exchange measured as current across the biological CELL MEMBRANE that has the capability to induce DEPOLARIZATION and hence activate the cell to perform its function. It is also known as RHEOBASE.

Rheological diagram

[fluid dynamics] Diagram outlining the flow classification of Newtonian versus non-Newtonian, as well as defining PLASTICITY; plotting the shear stress against the rate of deformation for a FLUID (see [Figure R.69](#)).

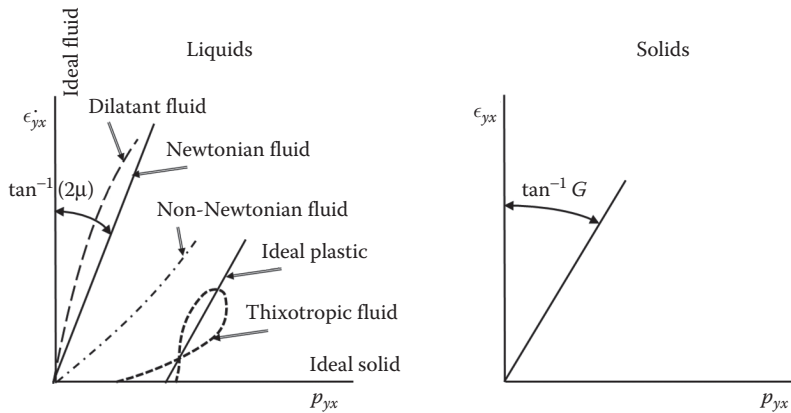


Figure R.69 Rheological diagram: illustrating the plastic flow (e.g., Bingham medium) under fluid-dynamic conditions response, rather than deforming elastically in response to an applied shear stress.

Rheology

[biomedical, computational, fluid dynamics, geophysics, mechanics, thermodynamics] Flow of inelastic condensed MATTER, also described as Bingham PLASTICS. The viscosity of the FLUID is flow velocity dependent and can be time dependent. Due to the nonlinear and inelastic nature this flow process is usually irreversible, the exception is generally for BLOOD flow, as a colloid SOLUTION flow. Blood flow changes with tube dimension (artery, arteriole, CAPILLARY, venule, VEIN, etc.) aspect ratio to the red blood CELL diameter. The flow of media that are subject to nonlinear behavior of shear stress and strain, also described by the Herschel–Bulkley model. Blood is the most recognized rheological LIQUID, other media include toothpaste, volcanic lava/magma flow, and make-up to name but a few.

Riccati, Jacopo Francesco; Count (1676–1754)

[computational, fluid dynamics] Mathematician from Italy. Count Riccati devised several expressions to perform differential equations with respect to quadratic expressions in an unknown function, the most well-known is the Riccati equation (see Figure R.70).



Figure R.70 Count Jacopo Francesco Riccati (1676–1754).

Riccati equations

[acoustics, computational, fluid dynamics, quantum] Mathematical first-order differential equation designed by COUNT JACOPO FRANCESCO RICCATI (1676–1754). The equation is quadratic in the unknown function that needs to be solved for. The general convoluted expression for the Riccati equation is given as $dy/dx = a^*(x) + b^*(x)y(x) + c^*(x)y^2(x)$, where $a^*(x)$, $b^*(x)$ and $c^*(x)$ are system-defining parameters, with respect to location-specific conditions. The Riccati equation reduces to the Bernoulli equation under certain conditions, and another example applies to the WAVE EQUATION in acoustic propagation in a geometry with curved walls. Other specific applications are found for solving the wave propagation for the SCHRÖDINGER EQUATION, respectively with respect to wave propagation in layered inhomogeneous media.

Richardson, Owen Willans, Sir (1879–1959)

[computational, solid-state] Physicist from Great Britain, known for his work on THERMIONIC EMISSION and the RICHARDSON'S EQUATION. Sir Richardson received the Nobel Prize in Physics for his thermionic emission work in 1928 (see [Figure R.71](#)).

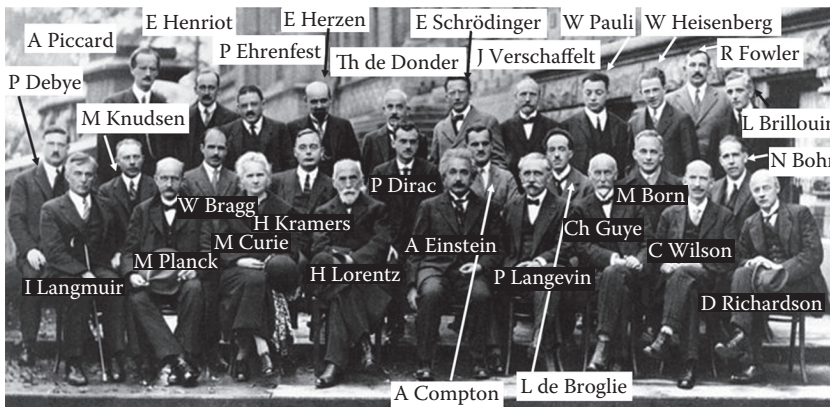


Figure R.71 Sir Owen Willans Richardson (1879–1959) at the 1929 Solvay Conference; Fifth Solvay International Conference on Electrons and Photons under chair Hendrik Lorentz (1853–1928), far right front row.

Richardson–Dushman equation

[thermodynamics] Relationship between the “free electron,” respectively ION thermionic emission with respect to the current density (J_s) through a CONDUCTOR and the work function (ϕ_w) of the emitting material as a function of temperature (T): $J_s = A_{RD} T^2 \exp(-\phi_w/kT)$, where $A_{RD} = 4\pi me k_b^2 / h^3$ the Richardson–Dushman coefficient (an indication of the PROBABILITY for release of charges per unit CROSS SECTION), and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann coefficient, m the electron mass, $e = 1.60217657 \times 10^{-19} \text{ C}$ the electron equivalent charge and $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT. Described by SIR OWEN WILLANS RICHARDSON (1879–1959), one particular application is in CATHODE emissions. The THERMIONIC EMISSION as initially described by the British scientist Frederick Guthrie (1833–1886) in 1873, later attributed to the scientist and statesman from the United States THOMAS ALVA EDISON (1847–1931) based on his published work in 1880. It is also known as Richardson equation.

Richardson's equation

[atomic, computational, nuclear] See RICHARDSON–DUSHMAN EQUATION. It is also known as RICHARDSON'S LAW.

Rician noise

[acoustics, biomedical, imaging, quantum] PROBABILITY distribution with respect to random signals generated as a result of nonlinear effects, providing a deviation from standard GAUSSIAN NOISE distribution. The Rician distribution specifically applies under MAGNETIC RESONANCE excitation and detection. Additionally, in ULTRASOUND imaging the random secondary resonance resulting from vibrational excitation is considered Rician noise. Rician noise takes into consideration the frequency distribution as well as the PHASE differences in the collected WAVE patterns with respect to the incident source, including the angular redistribution resulting from scatter. The Rician noise distribution is written as a function of the standard Gaussian distribution as $p_R(I_\ell(\vec{r})) = \left[I_\ell(\vec{r}) / \sigma_{sd} \right] \exp \left[- \left(I_\ell(\vec{r})^2 + A(\vec{r})^2 \right) / 2\sigma_{sd}^2 \right] \times J_0 \left(I_\ell(\vec{r}) A(\vec{r}) / \sigma_{sd}^2 \right)$, where $I_\ell(\vec{r})$ is the location-specific collected (noisy) SIGNAL magnitude, σ_{sd} the standard deviation with respect to the GAUSSIAN DISTRIBUTION, $A(\vec{r})$ the noise-free signal magnitude as a function of location (in approximation: $I_\ell(\vec{r}) = \sqrt{A(\vec{r})^2 + \sigma_{sd}^2}$); where the signal-to-noise ratio is defined as $SNR = A(\vec{r}) / \sigma_{sd}$, and $J_0(I_\ell(\vec{r}) A(\vec{r}) / \sigma_{sd}^2)$ a modified zero-order Bessel function of the first kind (see Figure R.72).

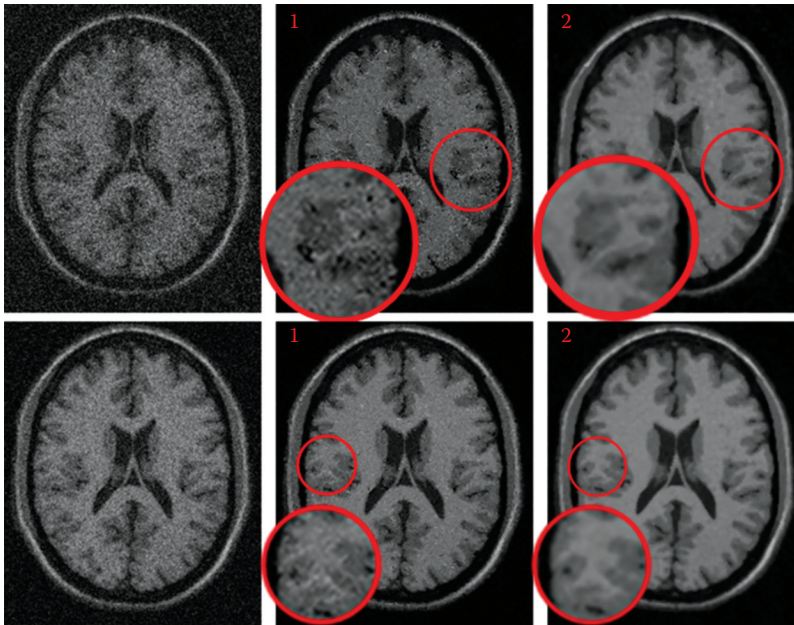


Figure R.72 Rician noise in MRI image outlined in detail focal areas. (Courtesy of Antonio Tristán Vega, submitted at Mathworks.)

Right-hand current rule

[general] Also see **RIGHT-HAND FORCE RULE**, which describes a different aspect. The direction of the **MAGNETIC FIELD** resulting from a current (virtual flow of positively charged particles) is indicated by the direction of the fingers when the hand grabs (encloses) the **POSITIVE CHARGE** flow (i.e., wire with current) and the thumb points in the direction of the current flow (see [Figure R.73](#)).

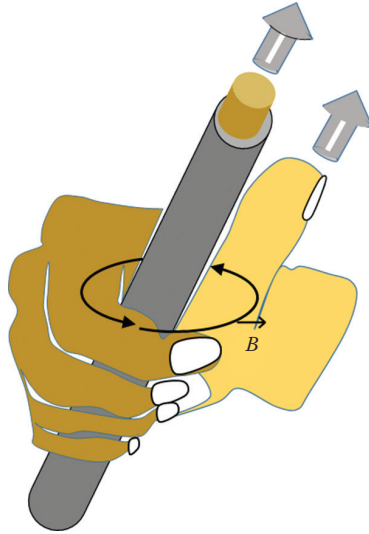


Figure R.73 Right-hand current rule.

Right-hand force rule

[general] The **FORCE** (F) applied on a current resulting from a moving charge (expressed as the charge q with velocity $\vec{v}$) in a **MAGNETIC FIELD** (B) follows the direction of the “lifted middle finger,” when the charge moves in the direction of the extended thumb and the **MAGNETIC field** point in the direction of the extended index finger, defined by $\vec{F} = q\vec{v} \times \vec{B}$. Also see **RIGHT-HAND CURRENT RULE**, which describes a different aspect (see [Figure R.74](#)).

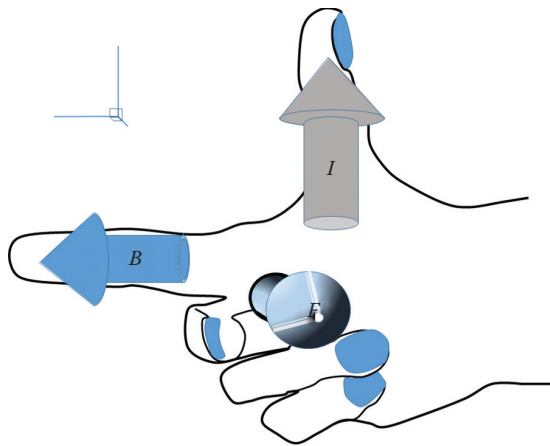


Figure R.74 Right-hand rule.

Ripple

[fluid dynamics] See **WAVE**.

Ritter, Johann Wilhelm (1776–1810)

[astrophysics/astronomy, general, optics] Discoverer of ULTRAVIOLET RADIATION in 1801 based on the work by the Swedish researcher CARL WILHELM SCHEELE, published in 1777. The work by Scheele describes the discoloration of paper coated with silver chloride when exposed to sunlight. Ritter also described the GALVANIC MECHANISM under the influence of LIGHT and he described the ELECTROLYSIS of water. Observations of current distributions in branched wires predate the publications by GEORG OHM (1789–1854) and GUSTAV KIRCHHOFF (1824–1887) (see [Figure R.75](#)).



Figure R.75 Johann Wilhelm Ritter (1776–1810), as he would have looked in 1804.

Riva-Rocci, Scipione (1863–1937)

[fluid dynamics] Physician from Italy. Inventor of the mercury SPHYGMOMANOMETER in 1896, device used to measure BLOOD PRESSURE (see [Figure R.76](#)).



Figure R.76 Scipione Riva-Rocci (1863–1937). (Courtesy of photographer Hans Christophersen and the Danish National Archive.)

Riva-Rocci cuff

[biomedical, fluid dynamics] Pressure cuff on the device introduced by **SCIPIONE RIVA-ROCCI** (1863–1937) for the **BLOOD PRESSURE** detection in the arm. The cuff is inflated and hence compresses the tissue surrounding the artery in the arm (brachial artery), thus restricting the blood flow. When the pressure is diminished the flow of blood in the artery intermittently, creating a **VIBRATION** of the vascular **WALL** similar to the **RESONANCE** of the an inflated balloon that is squeezed at the opening as **AIR** is escaping. The pressure in the cuff is raised above the known highest pressure recorded for any human heart before gradually reducing the pressure in the cuff over time. As the external pressure drops, instantly the blood will begin intermittent flow under the equilibrium condition where the applied pressure is equal to the **SYSTOLIC PRESSURE** applied by the **HEART**, not accounting from differences in height between the heart and the location of the pressure cuff and any inherent and residual flow **RESISTANCE** between the heart and the location of the pressure cuff, based on Bernoulli's law. Further reduction in pressure will eventually drop below the **DIASTOLIC PRESSURE**, at which point this will cause a cessation of the flow-induced vascular vibrations. In this manner the equivalent systolic and diastolic pressure for the individual is derived with relative accuracy. The device uses the **ACOUSTICS** resulting from the restricted and lack of blood flow using the vascular vibration identified by the Russian scientist **NIKOLAI SERGEYEVICH KOROTKOV** (1874–1920: Николай Сергеевич Коротков), known as the Korotkov sounds (see [Figure R.77](#)).



Figure R.77 Riva-Rocci cuff and Littmann stethoscope.

R

RMS value

[general] Root mean square, averaged value of **MAGNITUDE** of parameter using the weighted average of the square of all data points (n_i), by addition and divided by the number of data points, subsequently the square root is taken to yield the root-mean-square average: $\text{RMS} = \sqrt{\sum_{i=1}^N n_i^2 / N}$.

Roberval, Gilles Personne de (1602–1675)

[computational, general] Mathematician from France. The work of Gilles de Roberval was a prelude to modern mathematics ("infinitesimal calculus"). Additionally, the work of de Roberval supported the Copernican **HELIOCENTRIC** system; the **SUN** as the center of our planetary system, which was not fully accepted. The prior work of **NICOLAUS COPERNICUS** (1473–1543) also provided supporting evidence.

Gilles Personier (Personne) de Roberval was a contemporary of RENÉ DESCARTES (1596–1650), and they supported joint scientific beliefs (see [Figure R.78](#)).



Figure R.78 Gilles Personne de Roberval (1602–1675). Gilles de Roberval was a founding member of the French Academy of Sciences and the portrait was made during the inauguration in 1666; originally painted by Charles le Brun.

Robot

[acoustics, computational, electronics, fluid dynamics, mechanics, optics] Autonomous wired or wirelessly controlled device, respectively (*see* ROBOTICS) (*see* [Figure R.79](#)).

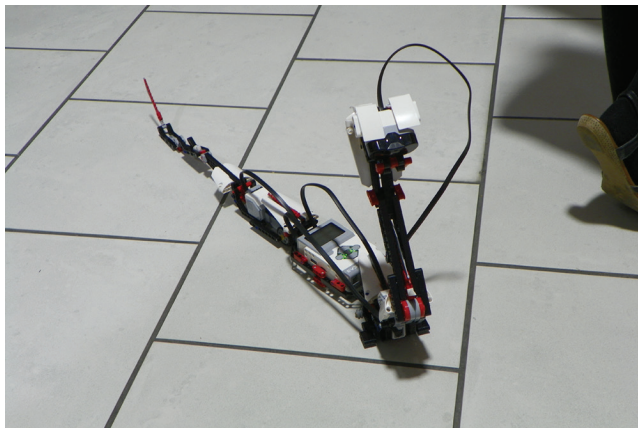


Figure R.79 Example of robots. Robot created by Zoe Crider.

Robotics

[acoustics, computational, electronics, fluid dynamics, mechanics, optics] Technological manifestation of mechanical devices that can operate by either remote control or independently under computer or MICROPROCESSOR (microchip) supported actuation, that is, ROBOT. Robots are devices that result from the integration of multifaceted aspects of a range of diverse technologies and ENGINEERING efforts, including but not limited to

MOTOR control, sensory PERCEPTION, information technology, cause-and-effect response autonomous “learning,” IMAGE acquisition, and data processing. The word “robot” originates from the play R.U.R. (Rossum’s Universal “Robots;” original title: Rossumovi Univerzální Roboti), by the Czechoslovakian writer Karel Čapek (1890–1938) published in 1920. The word robot originates from the Slavic word robota (and similarly also found in neighboring Cyrillic languages), which means “work” or “labor” (see [Figure R.80](#)).

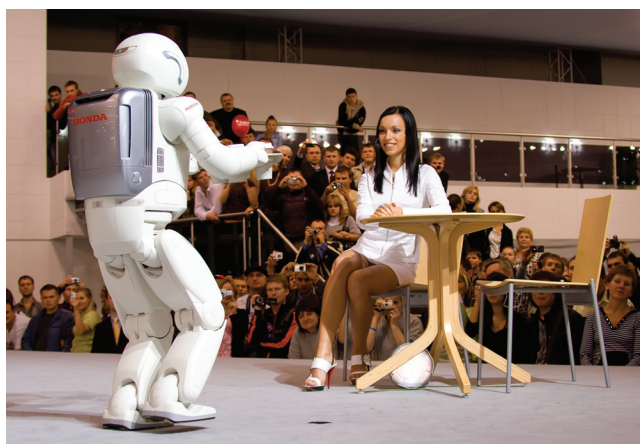


Figure R.80 House robot developed by Honda.

Rock salt

[condensed matter, solid-state] Mineral form of SODIUM CHLORIDE (NaCl , i.e., table SALT) and is also known as halite. The halite crystalline structure is primarily symmetric (see [Figure R.81](#)).



Figure R.81 Rock salt.

Rods

[biomedical, chemical, optics] Anatomical feature in the EYE responsible for the electrochemical conversion of the luminous intensity (i.e., radiance) of electromagnetic RADIATION in the PERCEPTION of shades of gray (see Figure R.82).

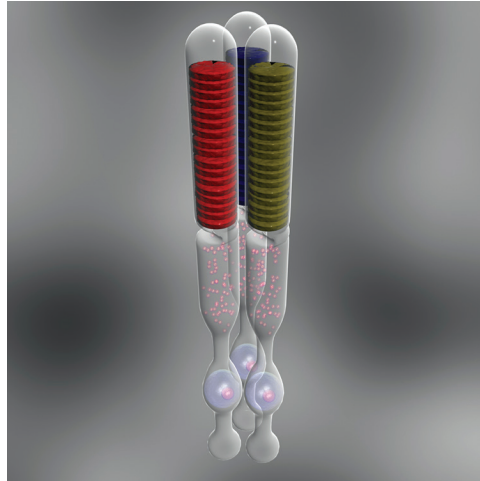


Figure R.82 Radiance sensor: rods of the retina in the eye.

Roemer {Rømer, also Römer}, Olaus (Ole) (1644–1710)

[astronomy, general, optics] Astronomer from Denmark. Ole Roemer concluded that the speed of LIGHT was finite and provided experimental proof with rudimentary equipment of this in 1675, the value obtained was $c = 2.0 \times 10^8$ m/s against the currently accepted value $c = 2.99792458 \times 10^8$ m/s. Roemer used the eclipse one of the largest observable moons of JUPITER, Io, based on the known distance between EARTH and Jupiter at that time. The MEASUREMENT of the speed of light was improved by ARMAND FIZEAU (1819–1896) in 1849 (see Figure R.83).



Figure R.83 Olaus Rømer {Ole Roemer} (1644–1710). (Courtesy of Leonardo Moledo, and portrait by Jacob Coning [circa 1647–1724 dated 1700]; Niels Bohr Institute, Denmark.)

Roentgen, Röntgen

[atomic, nuclear] X-RAY unit. The quantity of X-ray RADIATION which produces 1 esu positive or negative ELECTRICITY cm^{-3} or 3.2083×10^9 ion pairs/ cm^3 of AIR at standard temperature and pressure.

Roentgen, W. C.

[atomic, nuclear] See RÖNTGEN, WILHELM CONRAD.

Roentgen rays

[nuclear] See X-RAY.

Rolling friction

[general] RESISTANCE resulting from deformation of the object or the surface under rolling MOTION. The bulging of automobile tires is a common phenomenon of FRICTION, resulting in an increase in fuel consumption for the automobile, in contrast to solid rubber or low-profile tires. It is also known as “rolling resistance” (see [Figure R.84](#)).



Figure R.84 Rolling resistance examples.

Röntgen, Wilhelm Conrad {Roentgen} (1845–1923)

[atomic, biomedical, general, nuclear, solid-state] Physicist from Germany who described the discovery of X-RAY RADIATION. The discoveries by Röntgen made a remarkable and long lasting impact on solid media imaging, in particular medical imaging. Wilhelm Röntgen observed that the electron beam from a CROOKES TUBE generated other emissions when the electrons collided with the GLASS shell. The released particles were subsequently observed as FLUORESCENCE when exciting the barium platinocyanide coating. Röntgen subsequently recognized that the emitted radiation was capable of traversing paper, aluminum, wood, and other materials, and it would also form a chemical reaction with the photographic plates used for IMAGE formation using visible LIGHT. The new “undefined” X-ray was used to make images of the inside of several objects, including his wife’s hand, showing the bone structure outline on the imprint on the PHOTOGRAPHIC PLATE

consisting of silver chloride. Wilhelm Röntgen received the Nobel Prize in Physics for his discovery in 1901 (see [Figure R.85](#)).



Figure R.85 Wilhelm Conrad Röntgen {Roentgen} (1845–1923).

Rotational (divergence-free) vector field

[computational, fluid dynamics] A fundamental component of HELMHOLTZ DECOMPOSITION in vector calculus. In three-dimensional space, the vector field composed of sufficiently smooth, rapidly decaying vectors can be decomposed into the sum of two “orthogonal” components, one consisting of an IRROTATIONAL (CURL-FREE) VECTOR FIELD and the second segment composed of rotational (divergence-free) or solenoidal vector field (see DIVERGENCE-FREE VECTOR FIELD).

Roughness

[fluid dynamics, mechanics] See SURFACE ROUGHNESS.

Roughness, relative

[fluid dynamics, mechanics] See SURFACE ROUGHNESS.

Rouleaux formation

[biomedical, fluid dynamics] Plural for the French word for roll (i.e., roll of coins) *rouleau*, representative of the forming and maintaining of a stacked red BLOOD CELL in CAPILLARY FLOW (see [Figure R.86](#)).



Figure R.86 Rouleaux formation: stack of red blood cells in small vessel flow.

Rumford, Count (1753–1814)

[general] See **BENJAMIN THOMPSON**.

Runge, Carl David Tolmé (1856–1927)

[computational, general] Mathematician from Germany, known for his collaboration with another German mathematician **MARTIN WILHELM KUTTA** (1867–1944), both involved in the development of the **RUNGA–KUTTA METHOD** (see [Figure R.87](#)).



Figure R.87 Carl David Tolmé Runge (1856–1927).

Runge–Kutta method

[computational, theoretical] Numerical method for integrating nonlinear differential equations and hence providing means to solve them. The mechanism of action uses a conveniently chosen point in the coordinate system that allows integration to minimize the impact of lower order error terms. The method was designed by two mathematicians from Germany (Prussian Empire) CARL DAVID TOLMÉ RUNGE (1856–1927) and MARTIN WILHELM KUTTA (1867–1944) around 1900.

Russell, Bertrand Arthur William (1872–1970)

[general] Mathematician from Great Britain (see [Figure R.88](#)).



Figure R.88 Honorable Bertrand Russell (1872–1970) in 1916.

Russell, Henry Norris (1877–1957)

[nuclear] Astronomer from the United States (see [Figure R.89](#)).



Figure R.89 Henry Norris Russell (1877–1957). (Courtesy of The World's work; published by Doubleday Page, Garden City, New York.)

Russell–Saunders coupling

[atomic, computational, nuclear, quantum] In the orbital MECHANICS of the atomic structure the TOTAL ANGULAR MOMENTUM (J) for the electrons is the result of direct interaction between the ELECTRON SPIN angular momentum (S) and the orbital momentum (L) for that electron. The theoretical description of this phenomenon was developed by HENRY NORRIS RUSSELL (1877–1957) and FREDERICK ALBERT SAUNDERS (1875–1963). The angular momenta associated with the orbital MOTION as well as the SPIN motion can be combined in various manners. The integration of all aspects of these orbital and rotational states for atoms defined by a many electron configuration (Bohr model, Rutherford model) and how they contribute to the ENERGY state definition in a many-electron-atoms depends on three types of interactions: (1) spin–spin coupling, (2) orbit–orbit coupling, and (3) spin–orbit coupling. The two principal coupling schemes identified on a computational level are Russell–Saunders (or L–S) coupling and J–J COUPLING. Under Russell–Saunders coupling it is assumed that the following holds true: spin–spin coupling exceeds the influence over orbit–orbit coupling, which in turn trumps spin–orbit coupling. This approximation holds well for the first column in the table of ELEMENTS, where spin–orbit (J) coupling is relatively small and can be neglected. When the atomic number exceeds thirty (30) the j–j coupling takes precedent due to the fact that spin–orbit coupling becomes more influential. The overall electron spin QUANTUM NUMBER S is the sum of all individual SPIN quantum numbers m_s for the respective electrons, providing spin–spin coupling (first mechanism). The total ORBITAL ANGULAR MOMENTUM quantum number L defines the energy state described by the system composed of electrons, represented by the following terms (second mechanism):

TOTAL ORBITAL MOMENTUM						
L	0	1	2	3	4	5
	S	P	D	F	G	H

The third mechanism of spin–orbit coupling is defined by the resultant of the spin and orbital momenta of each electron which gives yields of the total angular momentum quantum number J . The interaction includes the concept of multiplicity, describing the closely spaced energy levels, defined by the term $(2S + 1)$. The Russell–Saunders expression associated with this coupling is $(2S + 1)L$, which can be described, for instance, using a d^1 electron configuration, where $S = +1/2$, $(2S + 1) = 2$, with respectively $L = 2$ and associated GROUND term 2D . The Russell–Saunders description for the remaining three “ION” configurations are represented as:

R

TERMS FOR THE RESPECTIVE $3d^n$ “FREE” ION CONFIGURATIONS				
CONFIGURATION	NUMBER OF ENERGY LEVELS	NUMBER OF QUANTUM STATES	GROUND TERM	WITH RESPECTIVE EXCITED TERMS:
$d^1; d^9$	1	10	2D	–
$d^2; d^8$	5	45	3F	$^3P; ^1G; ^1D; ^1S$
$d^3; d^7$	8	120	4F	$^4P; ^2H; ^2G; ^2F; 2 \times ^2D; ^2P$
$d^4; d^6$	16	210	5D	$^3H; ^3G; 2 \times ^3F; ^3D; 2 \times ^3P; ^1I; 2 \times ^1G; ^1F; 2 \times ^1D; 2 \times ^1S$
d^5	16	252	6S	$^4G; ^4F; ^4D; ^4P; ^2I; ^2H; 2 \times ^2G; 2 \times ^2F; 3 \times ^2D; ^2P; ^2S$

From this it can be seen that there is congruence between energy levels: d^n gives the same configuration term as d^{10-n} . The ground terms for the electron configurations are derived from Hund's rules: (1) ground term configuration will have maximum value for “multiplicity” and (2) when more than one term with maximum “multiplicity” is available, the ground term will be assigned the largest value for L . Outline of the interpretation of Hund's rule is as follows:

d^n	2	1	0	-1	-2	L	S	GROUND TERM
d^1	↑					2	1/2	2D
d^2	↑	↑				3	1	3F
d^3	↑	↑	↑			3	3/2	4F
d^4	↑	↑	↑	↑		2	2	5D
d^5	↑	↑	↑	↑	↑	0	5/2	6S
d^6	↑↓	↑	↑	↑	↑	2	2	5D
d^7	↑↓	↑↓	↑	↑	↑	3	3/2	4F
d^8	↑↓	↑↓	↑↓	↑	↑	3	1	3F
d^9	↑↓	↑↓	↑↓	↑↓	↑	2	1/2	2D

In order to derive S the values associated with the unpaired electrons need to be summarized using a value of $\frac{1}{2}$ for each. In order to derive L the labels in the respective columns are used to calculate the L value associated with that particular CELL in the table. Subsequently, summarize all respective cells. For instance, for the d^7 configuration the following applies. The +2 box has 2 electrons, yielding for that cell $L = +2 \times 2 = +4$; while the +1 box occupies 2 electrons, with respectively $L = +1 \times 2 = +2$, henceforth the 0 box has 1 electron: $L = 0$, the -1 box is 1 electron with $L = -1$, and finally the -2 box with 1 electron yields $L = -2 \times 1 = -2$, respectively $L = +4 + 2 + 0 - 1 - 1 = 3$. Note under the configuration of 5 electrons with 1 electron in each cell $L = 0$. The latter entails that the L -value for a d^1 configuration has the same configuration as for a d^6 . Alternatively, substitution of electrons with “holes” provides a platform to equate alternative electron configurations, such as conforming a d^1 configuration to a d^9 condition, where the d^1 case has one (1) electron and the d^9 case has a hole (i.e., absence of electron). From the L–S table it can be derived that there are 4D ground terms configurations (d^1, d^4, d^6, d^9). Similarly the F ground term has four configurations: (d^2, d^3, d^7, d^8), while the d^5 configuration provides for an S ground term (*also see L–S COUPLING*) (see Figure R.90).

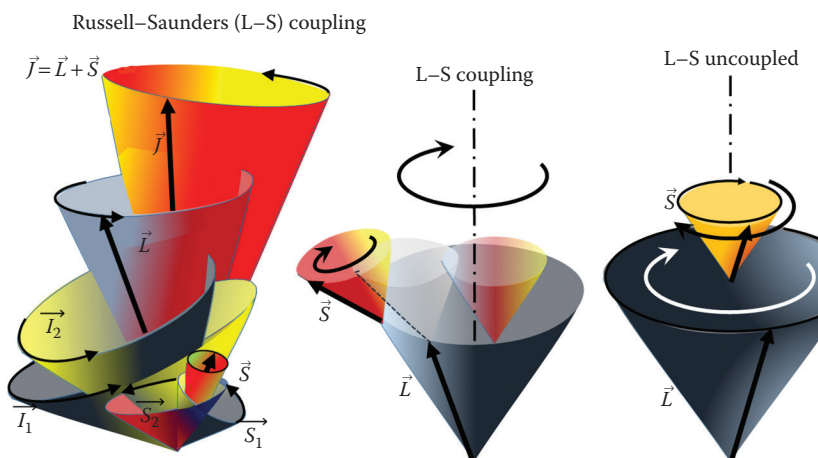
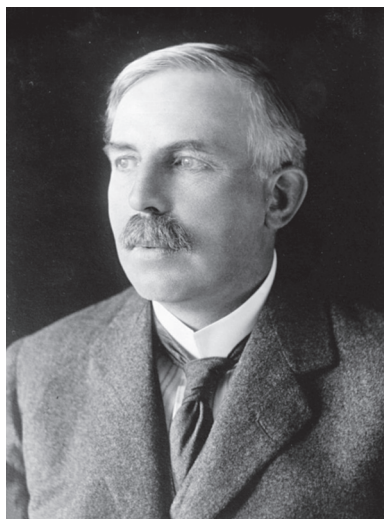


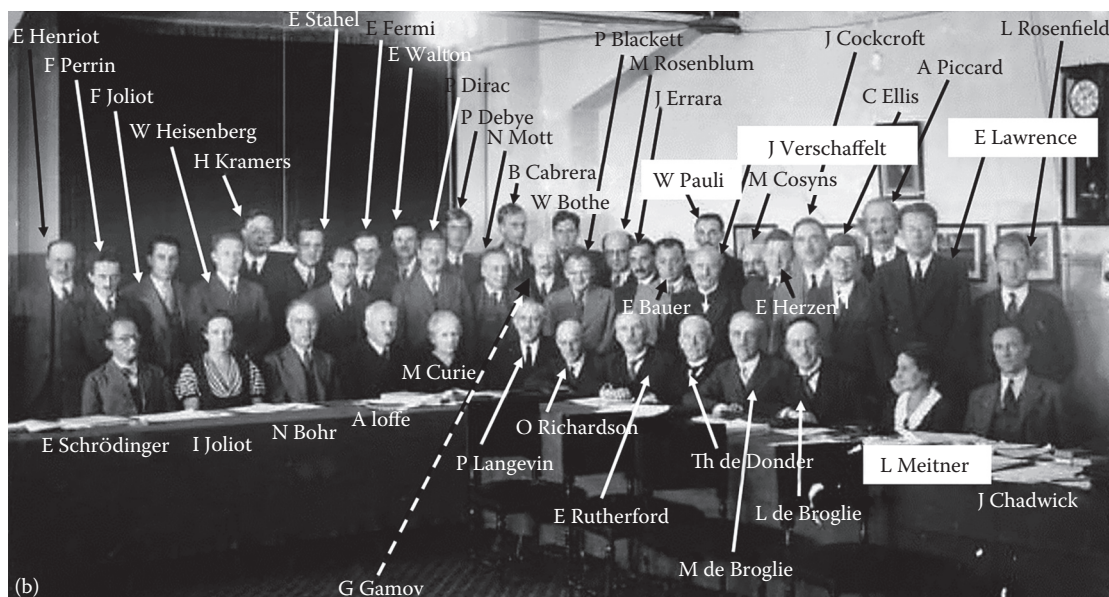
Figure R.90 Diagram representing Russell–Saunders coupling.

Rutherford, Ernest (1871–1937)

[general, nuclear, solid-state, thermodynamics] Scientist from New Zealand, apprentice of JOSEPH JOHN THOMSON (1856–1940); 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson. Recipient of the Nobel Prize in Chemistry in 1908. During his research in BECQUEREL RADIATION (the phenomenological description of radioactivity as discovered by HENRI BECQUEREL, 1852–1908, in 1896) he discovered the ALPHA PARTICLE (α) and defined the BETA PARTICLE (β). Rutherford is generally recognized as the leader in experimental nuclear PHYSICS. The PROTON was identified/postulated by WILHELM WIEN (1864–1928) in 1898, and named by Ernest Rutherford in 1920. The major contributions of Ernest Rutherford are the description of the nuclear HALF-LIFE and the conversion from one ELEMENT to another during NUCLEAR DECAY (see [Figure R.91](#)).



(a)



(b)

Figure R.91 Ernest Rutherford (1871–1937); in 1905: (a) United States Library of Congress's Prints and Photographs division under the digital ID gg Bain.36570, (b) at the 1933 Solvay Conference; Structure et propriétés des noyaux atomique: Structure and properties of the atomic nucleus; Chair Paul Langevin (1872–1946). (Courtesy of Department of Energy, Office of the Chief Financial Officer.)

Rutherford cross section

[atomic, nuclear] Respective scattering CROSS SECTION (finite size $d\sigma_s$) into a SOLID ANGLE ($d\Omega$) for the interaction with a PROJECTILE charged PARTICLE with a NUCLEUS with “size” (charge distribution related, the atomic number $[Z]$ multiplied with the proton charge $[e]$: Ze) with respect to an incident charge particle with atomic number Z_1 and velocity v_0 : $d\sigma_s/d\Omega = (Z_1 Z_2 e^2 / 8\pi\epsilon_0 m_\alpha v_0^2)^2 \csc^4(\theta/2)$, with the electron charge: $e = 1.60217657 \times 10^{-19} \text{C}$, the permittivity of free space: $\epsilon_0 = 8.85419 \times 10^{-12} \text{C}^2/\text{Nm}^2$, m_α the mass of the incident particle, the ALPHA PARTICLE, at deflection angle θ .

Rutherford scattering

[atomic, quantum] Based on the PARTICLE scattering distribution of Ernest Rutherford’s (1871–1937) bombarding of a gold foil with ALPHA PARTICLES, described as the ANGLE between the incident velocity of an alpha particle and the respective scattered velocity. The SCATTERING probability distribution as a function of the size of the NUCLEUS under target (i.e., the total charge; determined from the atomic number [“proton number”]: Z) for a charged PROJECTILE traveling with incident velocity v_0 , and mass m_α is presented in an angular (scattering angle: θ) representation as $P(\theta) = n(\theta)/n_0 = [Z_\alpha^2 Z^2 e^4 / 4(4\pi\epsilon_0)^2 m_\alpha^2 v_0^4] [1/\sin^4(\theta/2)]$, with the unit “electron” charge (identical for the PROTON, but opposite sign): $e = 1.60217657 \times 10^{-19} \text{C}$, the permittivity of free space: $\epsilon_0 = 8.85419 \times 10^{-12} \text{C}^2/\text{Nm}^2$, m_α the mass of the alpha particle (or in general the incident particle, with number of negative charges: Z_α), and v_r the recoil velocity of the nucleus. For the preverbal gold foil with thickness d_f and n_g gold atoms per unit volume, this translates into the angular probability ($N(\theta)$) for the collection of the number of scattered alpha particles ($N(\theta)$) at a return angle (θ), from a DISTANCE to the target nucleus (r), with respect to the incident beam of N_i alpha particles, each with kinetic ENERGY ($\text{KE}_\alpha = (1/2)m_\alpha v_0^2$) as $N(\theta) = (N_i n_g d_f Z^2 k_C^2 e^4 / 4r^2 \text{KE}_\alpha^2) [1/\sin^4(\theta/2)]$, with the Coulomb’s constant: $k_C = 1/4\pi\epsilon_0$, where: $\epsilon_0 = 8.85419 \times 10^{-12} \text{C}^2/\text{Nm}^2$ the permittivity of free space. The scattering concept provide a means to derive the size of the nucleus based on the “closest approximation distance” (d_0) for the incident charge with respect to the nucleus. At the closest approach the kinetic energy will be totally converted in potential energy for a brief moment, where the potential energy is the Coulomb energy: $U_p = (1/4\pi\epsilon_0)(Z_\alpha Z e^2 / d_0)$, which yields: $d_0 = (1/4\pi\epsilon_0)(Z_\alpha Z e^2 / mv_0^2)$. The closest distance of approach revealed deviations from a pure proton nucleus, and in 1920 the NEUTRON was introduced hypothetically by Rutherford, which was verified in 1932 and generally accepted in 1935 (see Figure R.92).

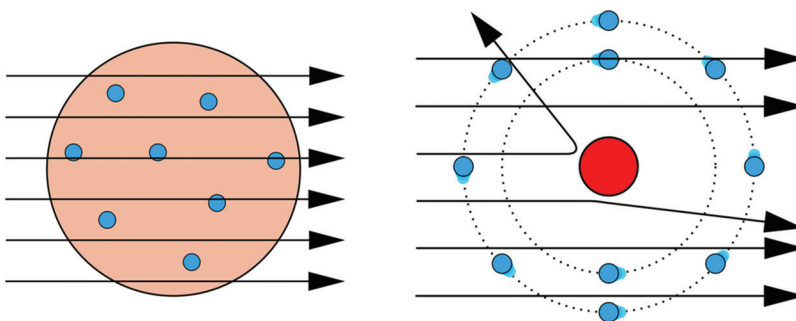


Figure R.92 Diagram representing the early concept of Rutherford scattering from the early 1900s.

Rutherford's atom

[general, nuclear, solid-state, thermodynamics] The ATOM consists of two main components: the NUCLEUS and orbiting "PLANET" electrons. This model was developed in parallel with the BOHR ATOMIC MODEL (see [Figure R.93](#)).

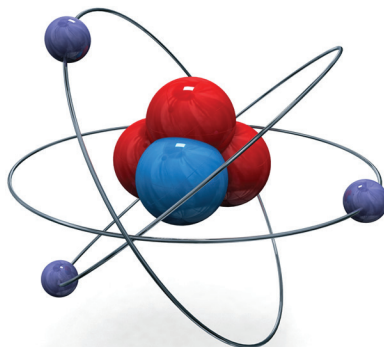


Figure R.93 Rutherford's "planetary" atom model.

Rydberg, Johannes Robert (1854–1919)

[atomic, nuclear] Physicist from Sweden. Johannes Rydberg provided elementary details about atomic structure and ENERGY configuration. Rydberg specifically introduced a constant that labeled the energy transitions used by various experimentalists, the RYDBERG CONSTANT. The Rydberg constant is used in the RYDBERG SERIES, and the BALMER SERIES, Humphreys series, LYMAN SERIES, PASCHEN SERIES, and PFUND SERIES (see [Figure R.94](#)).



Figure R.94 Johannes Robert Rydberg (1854–1919).

Rydberg constant

[atomic, general, nuclear, solid-state, thermodynamics] Fundamental constant describing the relationship between WAVELENGTH and ATOMIC NUMBER of an ATOM in the ELECTRON ENERGY TRANSITIONS occurring at the inner level of the BOHR ATOMIC MODEL, generating CHARACTERISTIC X-RAY RADIATION: $R_{\text{Ry}} = 1.097373 \times 10^7 \text{ m}^{-1}$. The value was derived by the Swedish scientist JOHANNES ROBERT RYDBERG (1854–1919) around 1890.

Rydberg series

[atom] Atomic ELECTRON DECAY introduced in 1888 by JOHANNES ROBERT RYDBERG (1854–1919) in general denomination, but primarily geared to hydrogen as

$$\frac{1}{\lambda} \Big|_{\text{vacuum}} = R_{\text{Ry}} \left[\left(\frac{1}{n_1^2} \right) - \left(\frac{1}{n_2^2} \right) \right] \xRightarrow{\text{generalized}} R_{\text{Ry}} Z^2 \left[\left(\frac{1}{n_1^2} \right) - \left(\frac{1}{n_2^2} \right) \right],$$

describing the decay RADIATION with wavelength λ emitted by the ENERGY lapse for an electron traversing from orbit n_2 to orbit n_1 ($n_1 < n_2$), with higher “BINDING” ENERGY, with RYDBERG CONSTANT $R_{\text{Ry}} = 2\pi^2 k_B^2 e^4 m_e Z^2 / b^3 c = 1.097373 \times 10^7 \text{ m}^{-1}$ $Z = 1$ for (Boltzmann coefficient $k_B = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$, electron charge: $e = 1.60217657 \times 10^{-19} \text{ C}$, electron mass: m_e , PLANCK’s CONSTANT: $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, and c the speed of LIGHT), and Z the charge of the hydrogen-like ATOM (see Figure R.95).

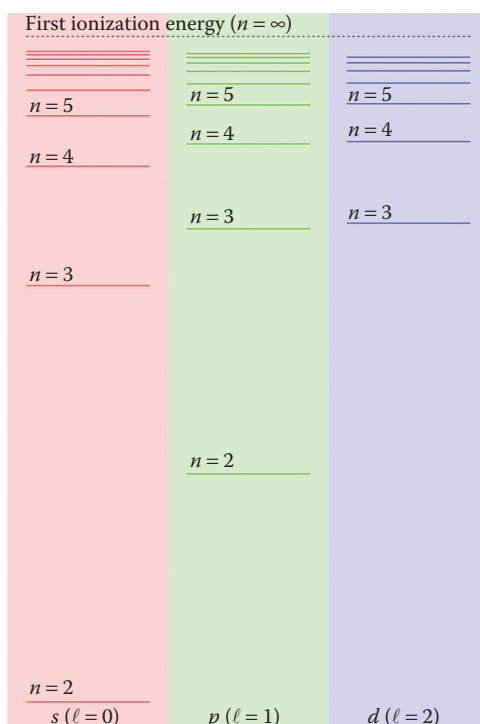


Figure R.95 Rydberg series for lithium. (Courtesy of DJ Indica.)

Rydberg state

[atomic, general, solid-state] Excited electron state in an ATOM or MOLECULE that provides an isolated energetic condition for that electron, resembling the state of an electron in a HYDROGEN ATOM. The electron acting as if it were a free electron has DECAY stages that have an ENERGY transfer resembling the RYDBERG SERIES.

Rytov, Sergei M. [РЫТОВ, Сергей Михайлович] (1908–1996)

[acoustics, computational, mechanics] Mathematician from the United Soviet Republic (USSR; now Russia). Sergei Rytov was best known for his PERTURBATION THEORY and WAVE propagation description with respect to nonuniform media (see [Figure R.96](#)).



Figure R.96 Sergei M. Rytov (1908–1996). (Courtesy of Kotelnikov Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Moscow, Russian Federation.)

Rytov approximation

[acoustics, computational] Ultrasonic TOMOGRAPHY algorithm using a perturbation of the PHASE of the WAVE in the WAVE EQUATION. Introduced by SERGEI RYTOV (1908–1996). This is of importance based on the assumption that wave transport will suffer DISPERSION due to inhomogeneities, specifically what is providing information about the acoustic parameters of the media in transit for the pressure wave ($P(\vec{r}, \nu)$), as a function of location $\vec{r}$ and frequency ν . In the wave equation the phase ($\phi(\vec{r}, \nu)$) of the pressure wave field is defined as $\phi(\vec{r}, \nu) \equiv \log_{10} P(\vec{r}, \nu)$. When an acoustic source $w(\vec{r}'', \nu)$ (acoustic perturbation with respect to location in second-order derivative) is applied the dispersion is captured as the reciprocal speed of propagation: $\vec{s}(\vec{r}, \nu) = 1/\vec{v}(\vec{r}, \nu)$. The acoustic propagation adheres to the wave equation: $[1/\vec{v}(\vec{r}, \nu)^2](\partial^2/\partial t^2)P(\vec{r}, \nu) - \nabla^2 P(\vec{r}, \nu) = w(\vec{r}, \nu)$, $w(\vec{r}, \nu)$ defining the VELOCITY POTENTIAL and DIVERGENCE. The unperturbed situation is described by $[1/\vec{v}(\vec{r}, \nu)^2](\partial^2/\partial t^2)P_0(\vec{r}, \nu) - \nabla^2 P_0(\vec{r}, \nu) = 0$. The wave equation has standard Green's functions as solutions: $G(\vec{r}, \vec{r}'', \nu)$; respectively $G(\vec{r}, \vec{r}', \nu)$ and $G(\vec{r}', \vec{r}'', \nu)$, in locations $\vec{r}$; $\vec{r}'$; $\vec{r}''$. The phase perturbation ($\partial\phi(\vec{r}, \nu)$) is now defined as $\partial\phi(\vec{r}, \nu)/\partial\vec{s}(\vec{r}', \nu) = \iiint 8\pi^2 \nu^2 \vec{s}(\vec{r}, \nu) G(\vec{r}, \vec{r}', \nu) G(\vec{r}', \vec{r}'', \nu) w(\vec{r}'', \nu) d^3\vec{r}'' / \iiint G(\vec{r}, \vec{r}''', \nu) w(\vec{r}''', \nu) d^3\vec{r}'''$. This yields for the pressure wave: $P(\vec{r}, \nu) = [1/\vec{v}(\vec{r}, \nu)^2](\partial^2/\partial t^2) \iiint \eta_c P_0(\vec{r}', \nu) G_0(\vec{r}', \vec{r}'', \nu) d^3\vec{r}''$, with η_c the “susceptibility” of the medium (“COMPLIANCE”) and $G_0(\vec{r}', \vec{r}'', \nu) = G_0(\vec{r}' - \vec{r}'', \nu)$ the Greens function SOLUTION to the unperturbed situation, in first-order approximation. In contrast the Born approximation uses perturbation of the AMPLITUDE.

S

S

[general] **DISTANCE** vector used in description of displacement $[\vec{s}]$. The absolute value is the **SCALAR** value of displacement, while the imaginary part describes the direction (see [Figure S.1](#)).

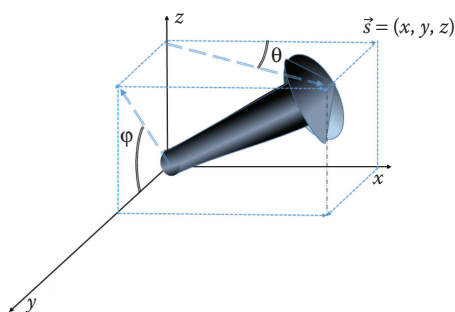


Figure S.1 s-vector.

S, M, and L responses of the human eye

[biomedical, general, optics] Layman's description of the **COLOR** vision by three sets of **CONES**: Short (-wavelength), *Medium* (-wavelength) and *Long* (-wavelength) representing the blue, green and **RED** cones (*also see VISION and see RETINA*).

Saberian number (Sa =)

[fluid dynamics] Dimensionless number signifying the **LIQUID** fraction applying to two-phased flow. The Saberian number is an indication of the "ease" with which a drop can be formed. Also applies to **SIGNAL** processing in neural networks.

Sabine equation

[acoustics, biomedical] Theoretical description of the time scale (reverberation time: RT) to allow a **SOUND** reverberating in a closed environment (volume V) to reduce by 60 dB while reflecting of walls with attenuation $\mu_{s,a}$, defined as $RT = k_s (V / \mu_{s,a})$, where k_s is the temperature dependence for the **WAVE** interaction. The temperature coefficient has been established to be $k_s = 0.161$ for a room temperature of 22°C.

Saccade

[biomedical, electronics, theoretical] Short deliberate movement across the field of view outlined by the azimuthal and the polar ANGLE in a spherical coordinate system. The saccade MOTION is regulated by the brain but is not necessarily something that is controlled by the desire of the subject. The duration of these EYE movement generally ranges from 100 to 300 ms and ranges over several degrees of rotation. The movement is both voluntary and involuntary, in contrast to the solely involuntary MICROSACCADE. The saccade can be a response to an incident in the peripheral VISION that makes the brain aware of a change in the status-quo that deserves attention, which can be considered a defense mechanism but also falls under the deliberate focusing of attention during a quick survey of one's perimeter. The main reason for saccade motion is avoiding "burn-in," where a group of RODS and CONES may get saturated from continued exposure and as a result will adjust their sensitivity down (sometime to the point of not detecting LIGHT anymore). In case SATURATION of the RETINA is induced the rods and cones become insensitive to exposure and form a risk of not being able to detect threats or challenges. Under strict concentration one can force the eyes to stay targeted without performing saccade motion (*also see MICRO-SACCADE*) (see [Figure S.2](#)).

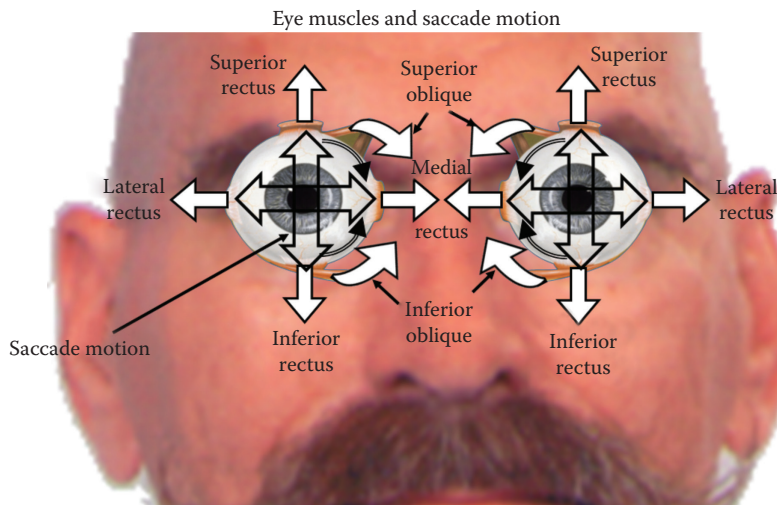


Figure S.2 Saccade motion of the eye. One way of observing this saccade motion yourself is with the use of an older model LED display calculator (Note: LCD screens do not blink and the visual aspect is hence not obvious). Looking straight forward (not following the calculator itself) move the calculator with at least one single display light-up in a straight up and down motion and the blinking lights will trace-out a curvy path up-down.

Saha, Meghnad (1893–1956)

[electronics, nuclear, thermodynamics] Indian astrophysicist. Saha's work describes the chemical and electronic balance in compounds as well as stellar structures including galactic dust. The ENERGY balance is defined by the Saha equation (see Figure S.3).



Figure S.3 Meghnad Saha (1893–1956).

Saha ionization equation

[astrophysics, electronics, nuclear, thermodynamics] Also Saha ionization equation, or Saha-Langmuir equation, developed by the Indian physicist MEGHNAD SAHA (1893–1956) in 1920. The Saha-equation describes the ratio of free charges to the number of electrons bound in atomic form, the IONIZATION fraction: $[\rho_e(x)\rho_i(x)]/\rho_a(x) = (1/nh^3)(2\pi m_e kT)^{2/3} e^{-[I/(kT)]}$, with $\rho_*(x)$ the ELECTRIC CHARGE density for the electrons ($* = e$), atoms ($* = a$) and ions ($* = i$) respectively and $I = (Z/n^2)(-13.6eV)$ the IONIZATION ENERGY, n the electron level in the BOHR ATOMIC MODEL, $k = 1.3806503 \times 10^{-23} \text{ m}^2 \text{ kgs}^{-2} \text{ K}^{-1}$ the Boltzmann constant, T temperature in Kelvin, m_e electron mass, and $h = 6.626068 \times 10^{-34} \text{ m}^2 \text{ kgs}^{-1}$ PLANCK'S CONSTANT.

Sahl, Ibn (Arabic: سهل ابن) (Abu Sa'd al-'Ala'ibn Sahl) (940–1000)

[mathematics, optics] Physicist and mathematician from Iraq, at the time known as Persia. The work of Ibn Sahl describes the LAW OF REFRACTION in a similar manner as attributed to WILLEBRORD SNEL (SNELLIUS) VAN ROYEN (1591–1626) (see [Figure S.4](#)).



Figure S.4 Artist impression of what Abu Sa'd al-'Ala' ibn Sahl (940–1000) may have looked like.

Saint-Elmo's fire

[atomic, energy] CORONA or charge streamer from a narrow pointy object (needle-like) such as the mast of a ship. It has also been observed on planes and in particular on helicopters, during the war in Afghanistan and was named Kopp–Echells effect by the photographer in honor of two soldiers who lost their lives there (see [Figure S.5](#)).



Figure S.5 Saint-Elmo's fire on top of a roof. (Courtesy of Joe Thomissen.)

Salt

[chemical, general] Chemical binding between a METAL and a halogen occurring in crystalline form as a solid and dissolves as ions in water. The most well-known salt is sodium chloride, or kitchen salt: NaCl.

SAM

[acoustics, biomedical] Imaging device based on the probing by focused MECHANICAL WAVE patterns. The propagation of SOUND through solids is a function of the local elastic properties, specifically the acoustic impedance which is a function of the wavelength of the density wave and the temperature next to the medium itself. The pressure wave or stress-wave propagation is indicated by the AMPLITUDE of the pressure at a point in the path of the WAVE. The migration of the stress wave is confined by the mechanical attributes of the media, that is, localized COMPLIANCE ($C = \partial V / \partial P$) or Young's modulus (E_{mech}) as a function of location. The time factor describing the propagation is called stress confinement or stress RELAXATION TIME, $\tau_s = \delta / V_a$, where V_a is the speed of sound in tissue. The acoustic transmission through the tissue layers is governed by the acoustic impedance, Z , a quantity defined as a product of density, ρ (tissue, temperature) and sound velocity, $v(v) = \sqrt{E_{\text{mech}} / \rho}$, yielding $Z = \rho v$ for the acoustic impedance. The acoustic impedance has a dispersive relation in inhomogeneous tissue, providing one of the elementary tools for diagnostic sensing. The RESOLVING POWER is directly proportional to the half wavelength of the probing sound wave. The sound is reflected from boundaries and dispersed and scattered to be analyzed by means of path reconstruction by means of time of flight measurements from array type sensor configurations (see SCANNING ACOUSTIC MICROSCOPE) (see Figure S.6).

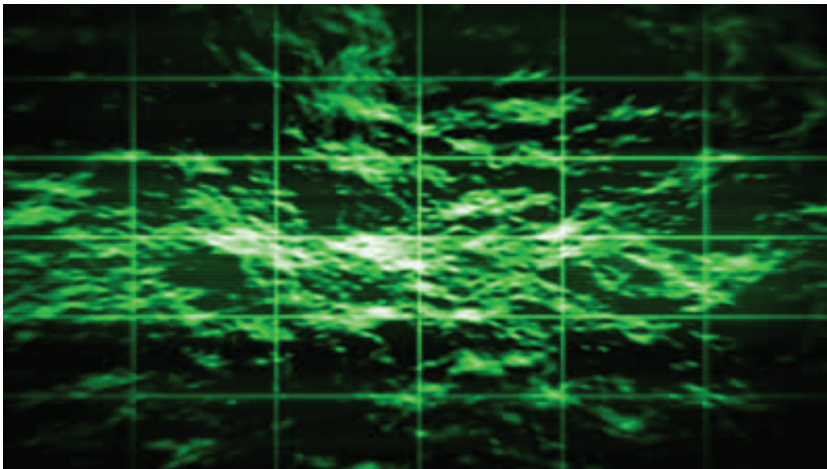


Figure S.6 Intensity profile image obtained by scanning acoustic microscope. (Courtesy of Ronald D. Kriz.)

Sampled delay focusing

[acoustics, computational] Ultrasonic BEAM-FORMING technique used with PHASED ARRAY pressure source which enables the emission of the SOUND WAVE to be confined within a narrow SOLID ANGLE (see PHASED-ARRAY).

Sampling

[acoustics, computational, electromagnetism, optics] The process of collecting data points. The sample data collection may be continuous or event-triggered. The limiting factor for discrete, periodic events (both spatial and temporal) is the minimum sampling rate, which is defined by the Nyquist sampling rate, or NYQUIST-SHANNON SAMPLING THEOREM. The minimum sampling rate used for a periodic event was defined

by HARRY NYQUIST (HARRY THEODOR NYQVIST; 1889–1976) and CLAUDE SHANNON (1916–2001) to be twice that of the minimum limit on the occurrence of an event within an observation composed of several events. The Nyquist sampling rate will provide two data-points for the definition of the location (i.e., spatial) or duration (resp. temporal) of a single event.

Sampling depth

[acoustics, computational, electromagnetism, optics] The depth from which SIGNAL is collected that has a signal to NOISE (background) ratio that provides useful information for accurate signal processing, meaning the phenomenon that is probed can be identified with scientific and clinical diagnostic limits of acceptance. Depending on the probing source configuration the sampling depth can range from micrometers to meters.

Sarcomere

[biomedical, chemical, mechanics] Elementary contraction unit in skeletal and HEART muscle. A MUSCLE fiber (e.g., SKELETAL MUSCLE) is a thin elongated cylinder with rounded ends and may extend the full length of the muscle. Beneath its sarcolemma (CELL MEMBRANE), the cytoplasm or sarcoplasm of the fiber contains many small, oval nuclei and MITOCHONDRIA. Within the sarcoplasm are numerous threadlike myofibrils that lie parallel to one another. They play an important role in muscle contractions. The myofibrils contain two kinds of protein filaments, thick ones composed of the protein MYOSIN and thin ones composed of the protein ACTIN. The arrangement of these filaments in repeated units are called sarcomeres, which produce the characteristic alternating LIGHT and dark striations of muscles. Light areas are the I-bands and the darker areas are A-bands. Z-lines are where adjacent sarcomeres come together and thin myofilaments of adjacent sarcomeres overlap slightly. Thus, a sarcomere can be defined as the area between Z-lines. Myosin filaments are located primarily within the dark portions of the sarcomeres, while actin filaments occur in the light areas (*see* MUSCLE) (*see* Figure S.7).

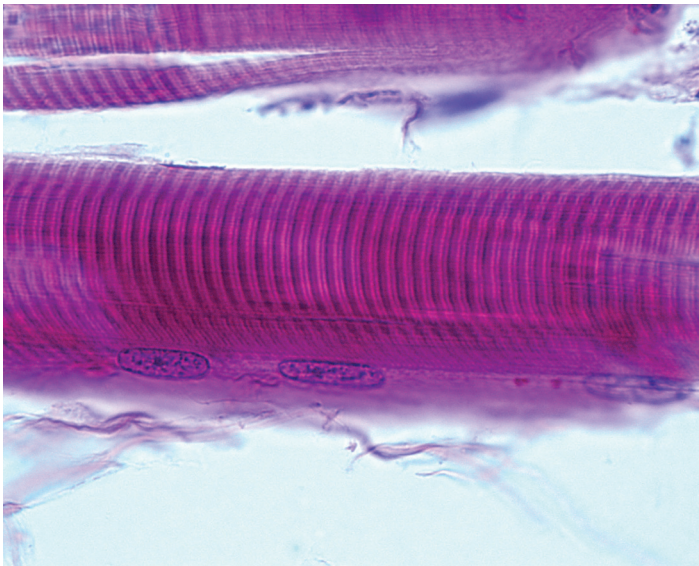


Figure S.7 Light microscopy magnified image of sarcomere in muscle.

Satellite

[astrophysics/astronomy, general] Word for artificial object launched from EARTH in orbit or at least in PROJECTILE motion horizontal to the earth's surface. The word "satellite" was introduced by JOHANNES KEPLER (1571–1630). Kepler's initial description of satellite MOTION were based on a model of a flat Earth, yielding a

parabolic trajectory. With current knowledge and verified ORBITS this is showing that all motions in space are primarily ellipsoids. The first EARTH SATELLITE defined as an electronic medium relaying signals from space to the Earth or from one location on Earth to another location beyond the horizon, was the Newton. Probably the most well-known satellite is the Russian (then USSR) space communication device Sputnik. Other applications are in observation (spy satellite, and METEOROLOGY). Satellites generally have no means of correction and are presumably placed in a geo-stationary or GEOSYNCHRONOUS ORBIT. However, due to gravitational pull and interaction with space debris the satellite may eventually return to Earth (see [Figure S.8](#)).

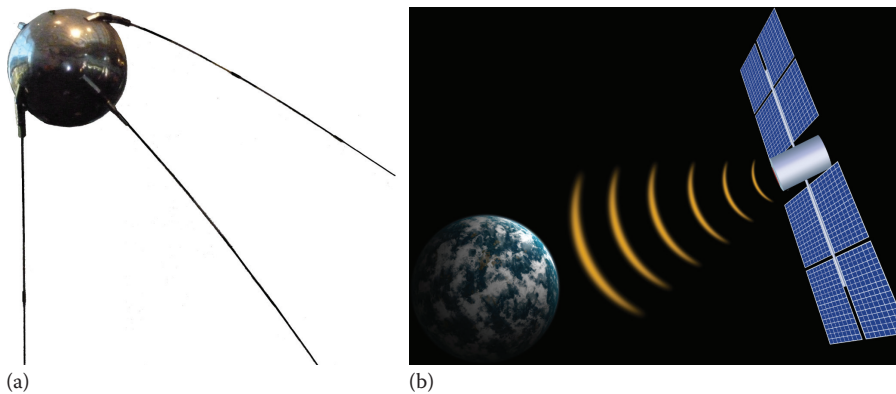


Figure S.8 Satellite: (a) Sputnik and (b) detail of general satellite in orbit around Earth.

Saturable nuclear force

[general, nuclear] One NUCLEON particle can only influence a limited number of closely neighboring particles, primarily based on the fact that the nucleon is totally surrounded by other nucleons, except for the nucleons at the “surface” of the NUCLEUS of the ATOM. This phenomenon is part of the short-range NUCLEAR FORCE.

Saturated state

[thermodynamics] A condition where the conditions would under normal conditions result in condensation (GAS) or AGGREGATION (dissolved SOLUTE) but due to the absence of condensation points refrains from changing state. For instance low temperature steam derived from cooling SUPERHEATED STEAM. The saturated state can be formulated by the EQUATION OF STATE for the equilibrium.

Saturated vapor pressure

[general] Situation where the GAS pressure of a medium is greater than the pressure in the LIQUID form of the medium at the boiling point. This condition may be achieved in a closed container. VAPOR PRESSURE increases with temperature, until at equilibrium the liquid comes to a boil. The liquid-GAS PHASE diagram as a function of volume of the container and the pressure at various temperatures is expressed in the Van der Waals diagram, supported under the Van der Waals equation (see PHASE DIAGRAM).

Saturation

[biomedical, chemical, mechanics, optics, thermodynamics] Critical range or point above which there is no linear increase of the parameter, identifying a maximum in the distribution function. In SOLUTION once saturation is reached the solutes start to crystallize and dissociate from the SOLUTE. When a force is in saturation there will be no increase in velocity. Under magnetization when saturation is reached there is no further increase in the MAGNETIC FIELD of the magnetic material. Soil acting as a sponge can only contain a

certain amount of LIQUID, where saturation sets in, above this point additional liquid will drain from the sponge, resulting in flooding. In visual PERCEPTION saturation of COLOR will indicate the “richness” of the perceived spectral profile of a source, which may be due to either illumination or pigment quantity content. A saturated GAS will precipitate a condensate, most well-known is fog and associated RAIN. In an IONIZATION chamber the production of ions can be saturated once the applied voltage captures all the produced ions without inducing additional ionization. In semiconductor operations an NPN TRANSISTOR can become saturated when the collector voltage is set at a level that is lower than the base voltage, hence making the collector change to emitter and the function of the TRANSISTOR is saturated. In a gas discharge the type of discharge will be regulated by the applied current, switching from GLOW-DISCHARGE to ARC DISCHARGE when a threshold is exceeded. In thermodynamic terms for instance water VAPOR at a certain temperature can be out of equilibrium with water, creating super-heated steam, or yielding condensation. Additional saturation in chemistry pertains to the maximum of chemical bonds created, or the maximum number of molecular products (see Figure S.9).

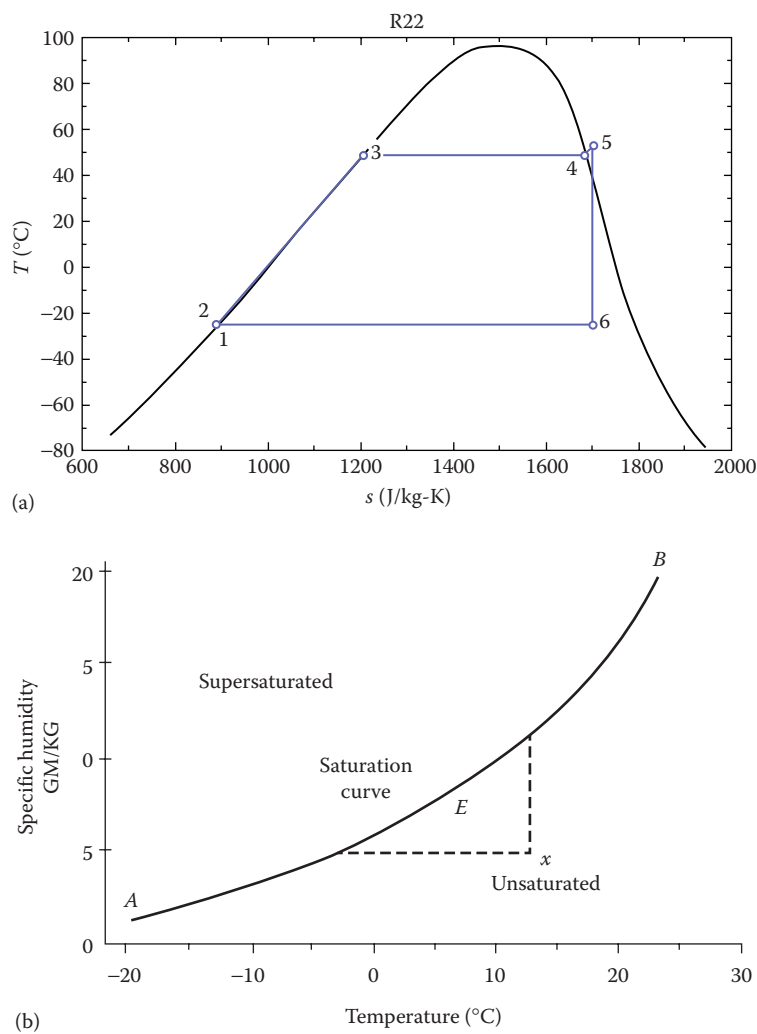


Figure S.9 (a–b) Saturation.

(Continued)

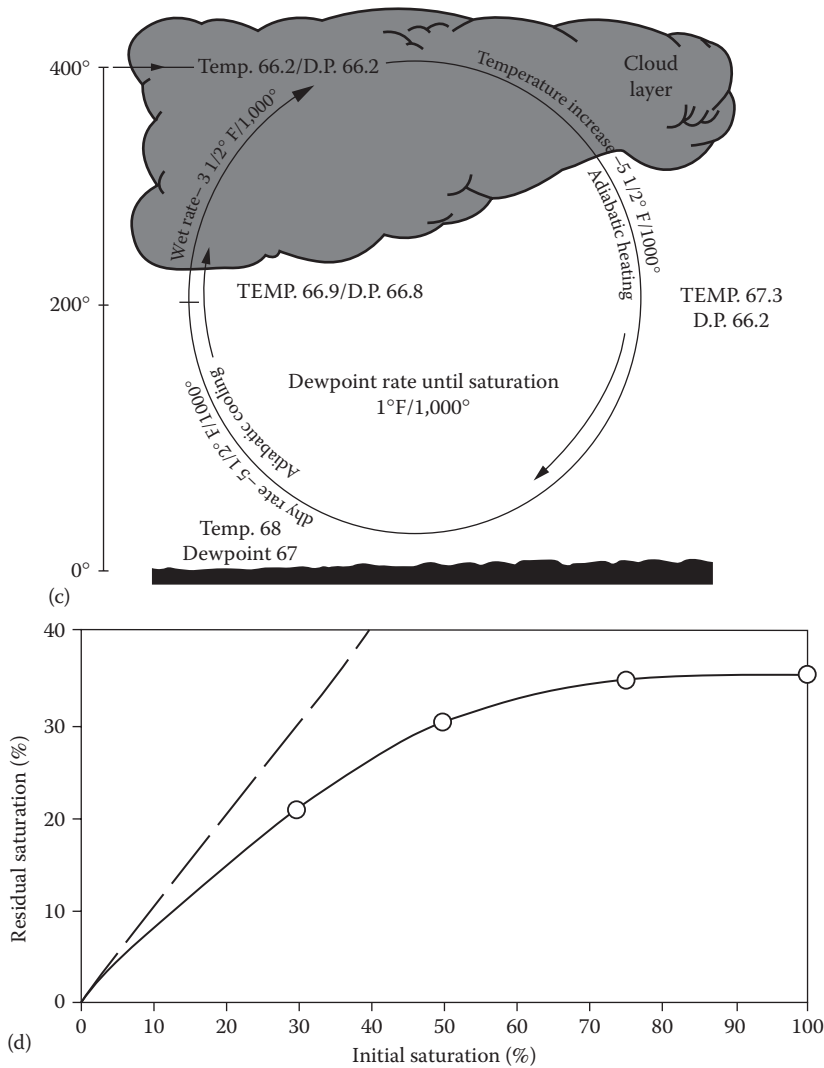


Figure 5.9 (Continued) (c-d) Saturation.

Saturation curve

[biomedical, mechanics, meteorology, thermodynamics] The SATURATION vapor curve describes the equilibrium between LIQUID and VAPOR in the T-S diagram, where T represents the temperature and S the entropy of the system. Alternatively the Michaelis-Menten saturation curve describes the chemical interaction in an enzymatic reaction, illustrating the plateau reached in the chemical reaction rate after a certain chemical quantity has been converted, resembling the charge curve of a CAPACITOR with an exponential/logarithmic temporal response. In biology the Oxygen binding to hemoglobin has a saturation leveling-off as a function of the partial pressure of the SOLUTE oxygen transferred in the alveoli of the lung into the blood-stream. The oxygen saturation is indicated by the Hüfner's constant ($\xi_{\text{Hüfner}} = 1.34$). BLOOD has a theoretical maximum capacity of binding oxygen of $= 1.39$ mL/gr. Additionally STRAIN-GAUGES have a response time that saturates when plotting the deformation (i.e., DISTANCE or arc) versus time. In geothermal applications

the formation of fog follows the RELATIVE HUMIDITY and the local temperature with respect to the rate in which fog is formed. In ELECTRONICS the response of an electronic circuit is plateauing as a function of frequency in alternating current drives such as RADIO frequency, radio, or television where the output at a certain point does no longer increase linearly with the driver input. A related principle applies to the charge accumulation on a capacitor as a function of time. An entirely different saturation is found in hydrocarbon AGGREGATION in the EARTH'S CRUST subsurface terrain. Hydrocarbon gasses and liquids are confined in four modes in particular: (1) GAS or OIL in volume storage, (2) oil or gas droplets in isolated form (e.g., suspended in gasses or on a surface, for instance through SURFACE TENSION), (3) hydrocarbon as solute in various liquids, and (4) suspended in kerogenous (porous) rocks. Specifically the dissolved and aggregated form of hydrocarbon content has a saturation curve per unit medium (see Figure S.10).

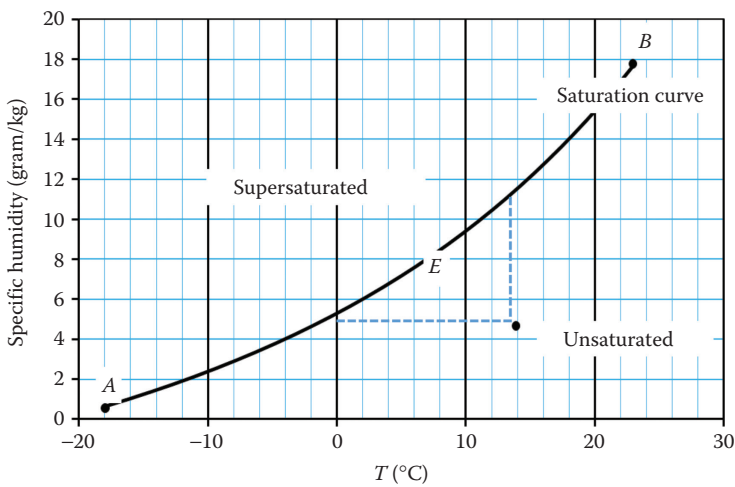


Figure S.10 Saturation curve diagram.

Saturation dome

[thermodynamics] Dome shaped relationship for the liquid-vapor equilibrium in a pressure–volume diagram (P–V diagram) with respect to temperature (see Figure S.11).

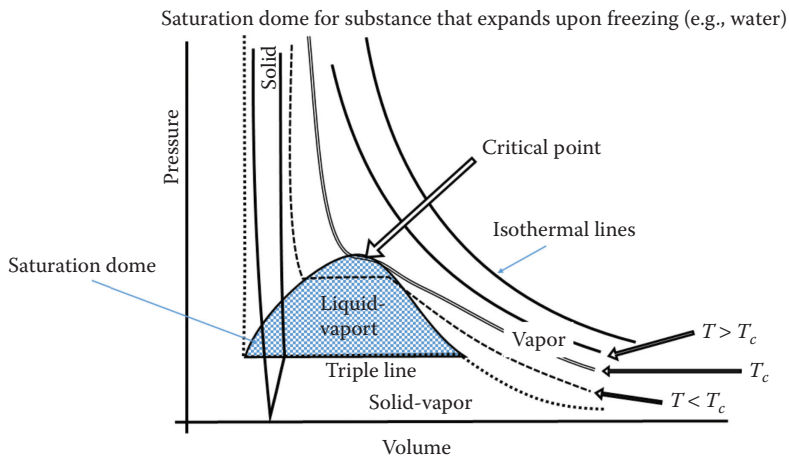


Figure S.11 Graphical representation of a saturation dome.

Saturation pressure

[thermodynamics] The optimal equilibrium pressure between LIQUID and saturated VAPOR in a confined environment (e.g., sealed container). The saturation pressure is a function of temperature, and volume as well as quantity of liquid (*see* PHASE DIAGRAM).

Saturn

[astrophysics/astronomy, general, mechanics] Sixth planet orbiting the SUN in our SOLAR SYSTEM, and second largest. The PLANET Saturn is the only planet with a seemingly infinite number of particles orbiting, compared the single MOON orbiting the third planet EARTH. Saturn has additionally in excess of 30 moons orbiting. The debris is held in orbit by gravitational pull. The galactic dust appears to form several confined rings of material grouping together. The rings of Saturn perform a WAVE MOTION similar to a tidal action which is one of the mechanisms that keeps the rings from coalescing. Note that most planets, moons, and comets form elliptic ORBITS for the reduction of stored angular momentum and rotational kinetic ENERGY to balance against the potential energy of the gravitational attraction in addition to minimal moment-of-inertia. Saturn revolves around the Sun in 29.42 earth-years, whereas its own revolution is 10.2 earth-hours. Due to the enormous angular velocity the planet is compressed the most out of all in the solar system with ellipsoidal ratio, oblateness: $R_{\text{oblate}} = (r_e - r_p)/r_e = 0.098$, where r_e is the equatorial radius and r_p the polar radius with equatorial diameter 120,540 km, whereas for Earth $R_{\text{oblate}} = 0.003353$. The mass of Saturn is $m_{\text{Saturn}} = 5.69 \times 10^{26}$ kg with a low density of $\rho_{\text{Saturn}} = 0.70 \text{ kg/m}^3$ (*see* Figure S.12).

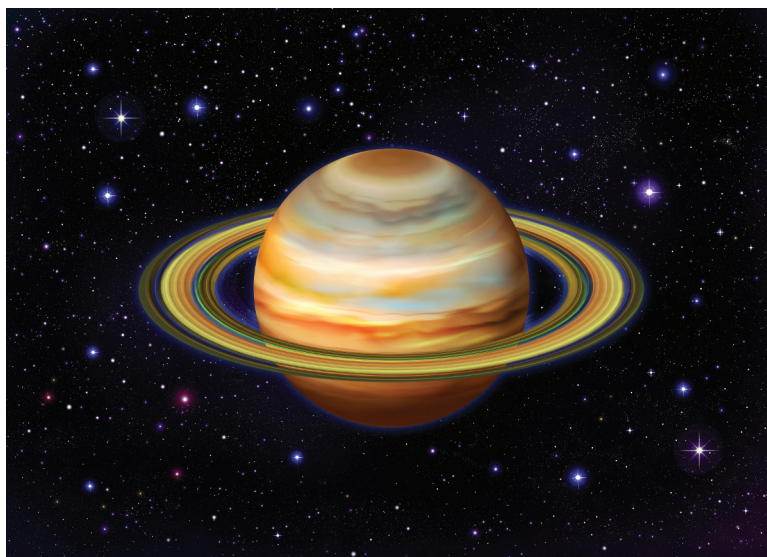


Figure S.12 Planet Saturn.

Saunders, Frederick Albert (1875–1963)

[computational, nuclear] Optical scientist and physicist from Canada, focused on SPECTROSCOPY. The work of Fredrick Saunders and HENRY NORRIS RUSSELL (1877–1957) describes the spectroscopic results from a specific atomic configuration that has more than one VALENCE electrons in the outer most shell (as described by the BOHR ATOMIC MODEL) that produce the spectral lines resulting from absorption and emission. The phenomenon is called RUSSELL-SAUNDERS COUPLING spectroscopy. Due to the plural electron configuration there are two momenta involved, the orbital (identified by the parameter L) and angular rotational SPIN (identified by the parameter S), hence also called L – S COUPLING.

Sauveur, Joseph (1653–1716)

[acoustics, computational, general, mechanics] computational physicist and mathematician from France. Even though he was deaf, his interest in the VIBRATION aspect of SOUND waves lead him to recognize that the RESONANCE FREQUENCY (ν) of a vibrating object primarily depended on the mass per unit length (m_l) next to the spring constant (k_{mech}) or ELASTICITY in deformation: $\nu = 1/2\pi \int_0^l \sqrt{(k/m_l)} dl$. His pioneering efforts in ACOUSTICS are known for the introduction of the concepts of FUNDAMENTAL FREQUENCY, harmonics, and node (see [Figure S.13](#)).

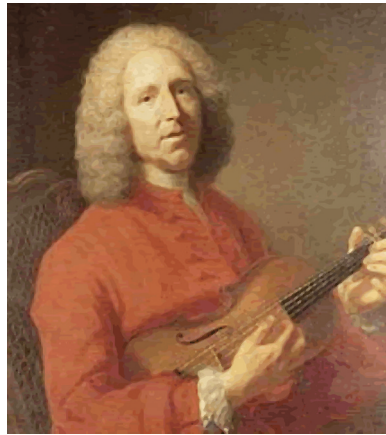


Figure S.13 Joseph Sauveur (1653–1716).

Savart, Félix (1791–1841)

[acoustics, electromagnetism, energy, general, mechanics] Physicist, medical doctor and engineer from France. He contributed to the understanding of ACOUSTICS as well as the behavior of magnetic fields and their interaction with paramagnetic materials. Together with JEAN BAPTISTE BIOT (1774–1862) they described the behavior of magnetic objects in a changing magnetic field, more precisely the MAGNETIC FIELD (B) distribution in space ($\vec{r}$) generated by a steady-state current ($\vec{I}$) flowing through a CONDUCTOR is known as the BIOT-SAVART LAW: $B = \mu_0 / 4\pi \int (\vec{I} \times \vec{r} / |\vec{r}|^3) dI$ for an integral over the length (l) of a conductor, where μ_0 is the DIELECTRIC permeability of VACUUM. Beyond the validity of the boundary conditions of the Biot–Savart approximation the JEFIMENKO'S EQUATIONS are the tools of the trade (see [Figure S.14](#)).

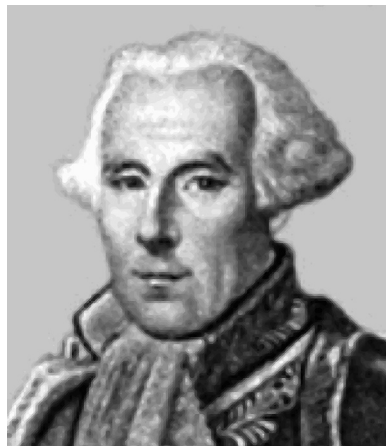


Figure S.14 Félix Savart (1791–1841).

Savery, Thomas (1650–1715)

[general, mechanics] “Captain Savery.” Inventor of a steam driven water pump ENGINE in 1698, the principle was based on the concept of the PRESSURE COOKER presented by DENIS PAPIN (1647–1712) from 1679, also called a Digester. The PUMP was designed to use VACUUM technique to pump water out of coal mines, however unsuccessful due to the limitations in height that could be overcome by the steam-vapor driven suction. Condensation of the water VAPOR at the raised outlet created a low level vacuum that pulled liquids upwards for discharge. Savery later teamed up with THOMAS NEWCOMEN (1664–1729), in collaboration with JOHN CALLEY (1644–1725), to develop the atmospheric reciprocating steam engine in approximately 1710. Other inventions by Savery include a mechanism to measure DISTANCE traveled for ships, also called an odometer for ships (see [Figure S.15](#)).



Figure S.15 Thomas Savery (1650–1715).

SAW

[acoustics] See SURFACE ACOUSTIC WAVE.

Scaffold

[biomedical, mechanics] In regenerative MEDICINE scaffolds are used to “grow” organs on, as internal permanent or biodegradable matrices. By carefully selecting the chemical structure of the materials that make up the fabric of the scaffold, CELL will adhere to the scaffold, forming a three-dimensional biological structure that conforms to the geometry of the scaffold as well as the genetic predisposition that can be implanted as a messenger to result in the formation of a single biological feature that can be used for transplant surgery. The natural scaffolds in biology are collagen and epithelial cells. Since the building blocks (i.e., cellular fundamentals from stem-cell sources) are from the person for whom the novel biological feature grown on the scaffold is intended for there will be minimal risks for rejection as a foreign body. Another particular application of biological scaffolds is in vascular grafts and prosthetics. The scaffold can be designed to disintegrate or remain intact, depending on the intended function and mechanical

requirements. In mechanical ENGINEERING a scaffold is also a mechanical construction that in this case allows for access to a structural formation, such as a building or an artwork that reaches above the reach of the people working on it (see [Figure S.16](#)).

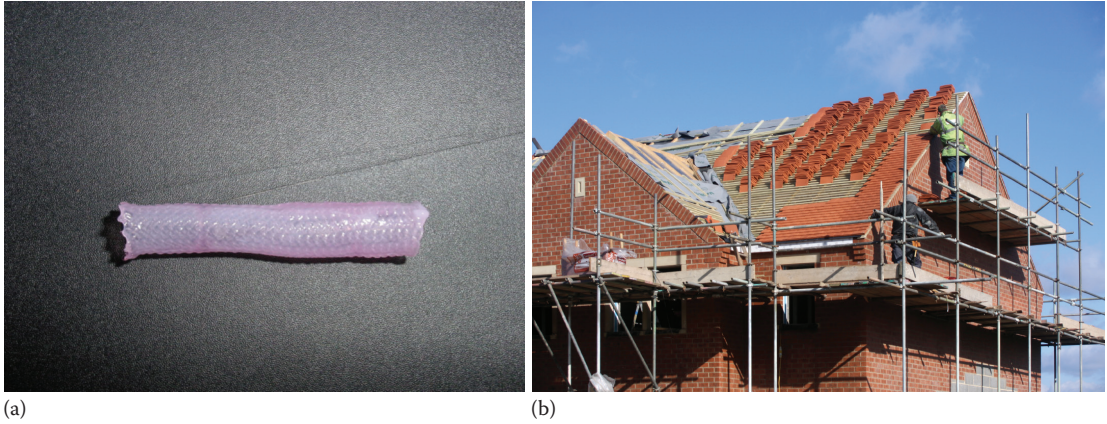


Figure S.16 Scaffold: (a) organ scaffold used in regenerative medicine to grow an arrangement of various tissues in a specified configuration and (b) metal building scaffold.

Scalar

[computational, general] Magnitude without direction, quantity. The alternate use would be a vector, which has both MAGNITUDE and direction.

Scanning acoustic microscope (SAM)

[acoustics, biomedical, mechanics] Imaging device based on the probing by focused MECHANICAL WAVE patterns. The propagation of SOUND through solids is a function of the local elastic properties, specifically the acoustic impedance which is a function of the wavelength of the density wave and the temperature next to the medium itself. The pressure wave or stress-wave propagation is indicated by the AMPLITUDE of the pressure at a point in the path of the WAVE. The migration of the stress wave is confined by the mechanical attributes of the media, that is, localized COMPLIANCE ($C = \partial V / \partial P$) or Young's modulus (E_{mech}) as a function of location. The time factor describing the propagation is called stress confinement or stress relaxation time, $\tau_s = \delta / V_a$, where V_a is the speed of sound in tissue. The acoustic transmission through the tissue layers is governed by the acoustic impedance, Z , a quantity defined as a product of density, ρ (tissue, temperature) and sound velocity, $v(v) = \sqrt{E_{\text{mech}} / \rho}$, yielding $Z = \rho v$ for the acoustic impedance. The acoustic impedance has a dispersive relation in inhomogeneous tissue as well as composite materials, providing one of the elementary tools for diagnostic sensing. The RESOLVING POWER is directly proportional to the half wavelength of the probing sound wave. The sound is reflected from boundaries and dispersed and scattered to be analyzed by means of path reconstruction by means of time of flight measurements from array type sensor configurations. The incident acoustic wave used in mechanical acoustic microscopy can be generated by piezoelectric devices and requires focusing techniques to enhance the RESOLUTION, since the resolution will be restricted by the width of the acoustic beam. The mechanically produced

acoustic wave will need to be coupled into the imaging medium by means of a medium that provides acoustic impedance matching. The use of water is routine, however liquid helium can significantly enhance the LATERAL RESOLUTION by an order of MAGNITUDE. The acoustic SIGNAL retrieval is primarily performed by piezoelectric sensing arrays. The use of large APERTURE acoustic lenses for signal retrieval can provide radial resolution enhancement through INTERFERENCE inside the “LENS.” The reconstruction process is based on inverse SCATTERING theory and time-resolved detection used for phase analysis. A Scanning Laser Acoustic Microscope (SLAM) uses a pulsed laser to generate the acoustic pulses (photoacoustic effect) resulting from localized EXPANSION due to the absorption of LIGHT, and the laser is scanned across the medium under interrogation for a three-dimensional reconstruction of the mechanical properties. As in ULTRASONIC IMAGING the operating FREQUENCY SPECTRUM is in the MHz to GHz range. Based on the scanning laser acoustic microscope another modality was added with special emphasis on the PHASE detection of the acoustic wave resulting in the Scanning tomographic acoustic microscope (STAM); also found as Scanning Acoustic Tomography (SAT). Due to the random phase of the acousto-optical pulse the constraints for the tomographic imaging are in the theoretical analysis and the use of multiple arrays of sensors to perform scattered wave reconstruction, based on both time-of-flight and phase-sensitive detection. Acoustic microscopy can be used for nondestructive testing, revealing the REFLECTION from MICROSCOPIC cracks and stress and strain anomalies (*also see PHOTOACOUSTIC IMAGING*) (see Figure S.17).

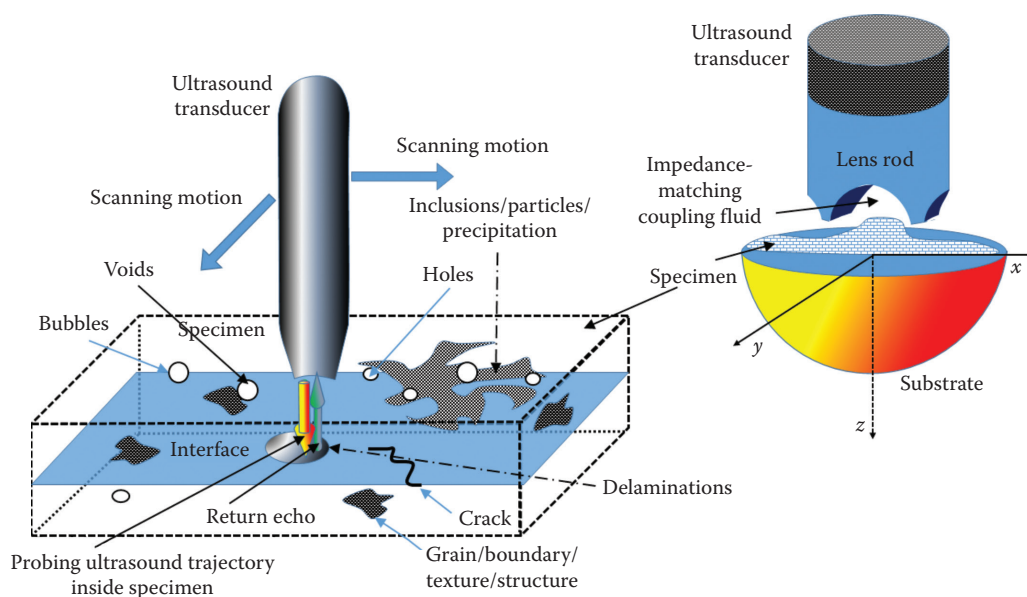


Figure S.17 Scanning acoustic microscope design and implementation.

Scatchard, George (1892–1973)

[biomedical, chemical] Scientist and chemist from the United States. Scatchard made significant contributions in physical chemistry of solutions. He focused on the theoretical explanation of steady-state solutions in equilibrium and nonsteady-state solutions, ranging from simplest mixtures of nonpolar molecules to

systems containing polar molecules of various degree as well as ions, and he also included MACROMOLECULES, specifically the unexplored area of proteins (see Figure S.18).



Figure S.18 George Scatchard (1892–1973). (Courtesy of Chemical Heritage Foundation, Philadelphia, PA.)

Scatchard equation

[biomedical, chemical] Formulation of the LIGAND affinity to the distribution of various proteins. $r_{l_b}/c_l = nK_a - rK_a$, where r_{l_b} is the ratio of the concentration of bound ligand to the number of available binding sites, c_l the free ligand concentration, $K_a = [A_b - A_g]/([A_b][A_g])$, where $1/K_a$ is the slope and is the affinity constant, with $[A_b]$ the concentration of antibody binding-sites, $[A_g]$ the antigen concentration (monovalent), $[A_b - A_g]$ the concentration of antigen bound to anti-body, and n is the number of binding sites per protein MOLECULE. Introduced by GEORGE SCATCHARD (1892–1973). This expression is equivalent to the one of the three linear transformations of the MICHAELIS-MENTEN EQUATION.

Scatchard plot

[biomedical, chemical] Plot of specific binding bound ligands versus the ratio of specific binding (bound ligands) with respect to the concentration of free ligands; that is, “bound in correlation to free.” Introduced by GEORGE SCATCHARD (1892–1973) (also see MICHAELIS–MENTEN KINETICS [MICHAELIS–MENTEN EQUATION]) (see Figure S.19).

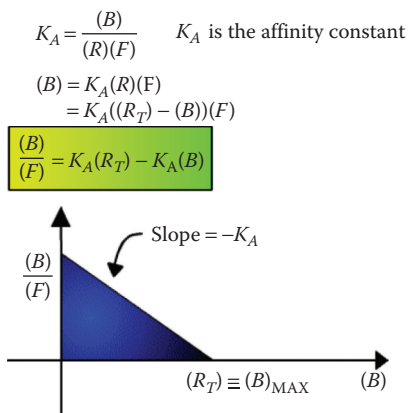


Figure S.19 Scatchard plot. (Courtesy of Stanford Medicine. http://mips.stanford.edu/courses/pharmacokinetics/Nonlin_comp/Rec_Lig_plex/2.html.)

Scatchard–Rosenthal plot

[biomedical] See **SCATCHARD PLOT**.

Scattering

[acoustics, astrophysics/astronomy, general, nuclear, optics] Redirection of the trajectory of **ENERGY** either lossless or lossy. The scattering mechanism is primarily based on diffuse discontinuities and nonuniformities in a medium of transport, which can be subatomic in size. The **MAGNITUDE** of interaction can be very locally diverse, rendering the observation an average over the selected size of the volume of interaction. The energy can be the representation of a **PARTICLE** moving with velocity v , or electromagnetic or acoustic energy. **COMPTON SCATTERING** describes the particle scattering during interaction with the **NUCLEUS**, where optical scattering involves the remittance of photons after resonant coupling with atomic and molecular constituents of a medium, such as tissue. The “**EQUATION OF RADIATIVE TRANSFER**” or “**Radiative Transfer Equation**” describes the **PROBABILITY** of redirection within a **SOLID ANGLE** for either galactic dust or biological media. Scattered **ACOUSTIC WAVES** are usually plagued by **DISPERSION** resulting from stress and strain in the medium, partially due to the acoustic density distortions themselves. The scattering phenomenon has a probability distribution which ties directly to a mean-free path-length. The mean-free path-length is an indication of the **DISTANCE** over which there are no anticipated interactions of both scattering or absorption. Optical scattering has been classified under two main formats: **RAYLEIGH SCATTERING** and Mie scattering, where the Rayleigh scattering pertains to small particle interaction and Mie scattering is more **MACROSCOPIC** (see [Figure S.20](#)).

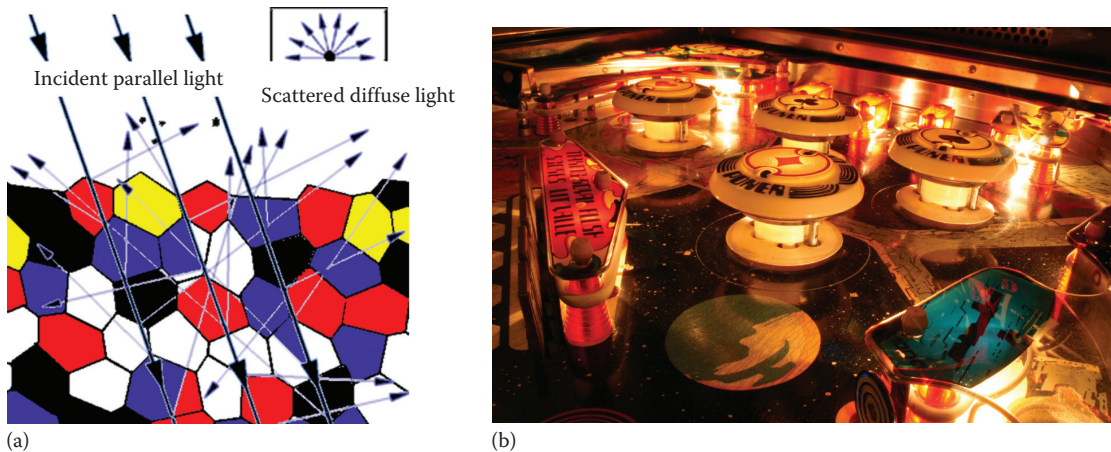


Figure S.20 (a) The scattering concept exemplified and (b) pinball machine analogy how a photon is scattered by atoms in a turbid medium. (Note: A hole in the surface would represent absorption.)

Scattering cross section, Rayleigh

[general, optics] In case electromagnetic waves interact with particles that are smaller than the wavelength, the **LIGHT** is not necessarily absorbed, it will most likely be scattered. The **ELASTIC SCATTERING** of electromagnetic **RADIATION** on particles smaller than the wavelength is described by the work of the English mathematician **JOHN WILLIAM STRUTT LORD RAYLEIGH** (1842–1919). Lord Rayleigh made an effort to explain the appearance of the blue sky and red sunset in his work published in 1871. His approximations were based on the assumption that electromagnetic waves interacted with items smaller than the wavelength, the atomic dimensions of the gasses in the upper **ATMOSPHERE**.

Scattering length, singlet

[nuclear] In the NUCLEON scattering process the interaction of the ENERGY stream with the discontinuity or perturbation can be viewed for ELEMENTARY PARTICLES such as proton—proton two-body interaction is defined by the strength of the interaction, or the likelihood of the event to take place and at what energy transfer, defined by the scattering length. During the interaction of particles with simple SPIN configuration the SCATTERING process is strictly defined in a uniform energy approach. For atoms colliding with relative momentum $p = k\hbar$, the scattering length (a_{scat}) is related to the s -WAVE PHASE shift δ_0 defined as $a_{\text{scat}} = -\lim_{k \rightarrow 0} (\tan(\delta_0/k))$, where $k = 2\pi/\lambda$ is the wavenumber, λ the wavelength (deBroglie wavelength), and $\hbar = h/2\pi$; $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ PLANCK'S CONSTANT.

Scattering length, triplet

[nuclear] In the NUCLEON scattering process the interaction of the ENERGY stream with the discontinuity or perturbation can be viewed as nucleon—nucleon interaction that may take place with certain PROBABILITY, defined by the scattering length. During the interaction of nucleons with complex spin configuration the SCATTERING process needs to be defined with respect to the spins involved and the SPIN conversion probabilities. A nucleon with a spin TRIPLET STATE will have the probability for exchanging angular momentum in various formats and the energy configuration can be arranged in spin triplet channels. Each channel will be bound by a critical momentum for interaction. For resonant interaction this interaction length can be several hundred Bohr radii, yielding a high probability with significant exchange of energy, as a direct function of the interaction potential.

Scattering phase function

[astrophysics/astronomy, computational, optics] $p(\vec{s}, \vec{s}')$, is defined by the ANGLE (θ) between the direction of the rays incident on a sphere of medium ($\vec{s}$) with small but finite dimensions and the exiting, redirected rays with vector designation $\vec{s}'$: $\theta = \vec{s} \cdot \vec{s}'$. The PHASE function $p(\nu, \nu')$, is a function of the SCATTERING angle θ only, and can be expanded in a series of Legendre functions to the order n (which in fact represents the order of scattering events), where the following substitution has been made: $\nu = \cos \theta$; $p(\nu, \nu') = 4\pi \sum_0^\infty [1/(2n+1)] w_n p_n(\nu) p_n(\nu')$, where w_n is the scattering albedo, $w_0 = \mu_s/(\mu_a + \mu_s)$ the albedo of single scattering, with μ_s the scattering coefficient of the medium and μ_a the absorption coefficient (see Figure S.22).

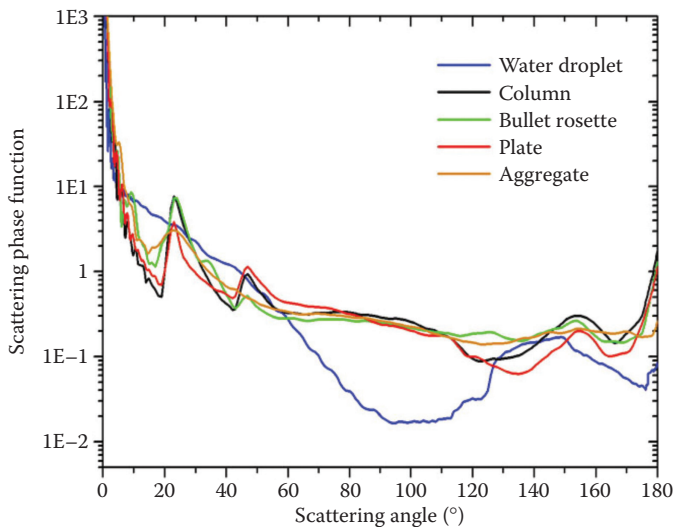


Figure S.22 Scattering phase function. Scattering phase function of different ice crystals in comparison to water droplets at wavelength of 700 nm and a particle dimension of 95 μm . (Courtesy of André Ehrlich, University of Leipzig, Leipzig, Germany.)

Scattering phase function, Henyey-Greenstein

[astrophysics/astronomy, biomedical, computational, optics] The Henyey–Greenstein scattering phase function has been shown to be a good approximation of the true PHASE function of biological tissue and is given by $P_{\text{HG}} = (1/4\pi)[(1 - g^2)/(1 - 2g\mu^* + g^2)^{3/2}]$, where g is the mean cosine of the scattering ANGLE (anisotropy factor: $\langle \cos \theta \rangle$) and $\mu^* = \vec{s} \cdot \vec{s}' = \cos \theta$. A plot of the scattering phase function P_{HG} on a polar diagram represents the angular distribution of the scattering angle for an infinite medium and an infinite number of photons.

Schawlow, Arthur Leonard (1921–1999)

[optics, solid-state] Physicist from the United States. Arthur Schawlow was instrumental in the development of the predecessor to the LASER, the MASER (Microwave Amplification by Stimulated Emission of Radiation) introduced in 1954 in collaboration with CHARLES HARD TOWNES (1915–), for which they both received the Nobel Prize in Physics in 1964 (see [Figure S.23](#)).

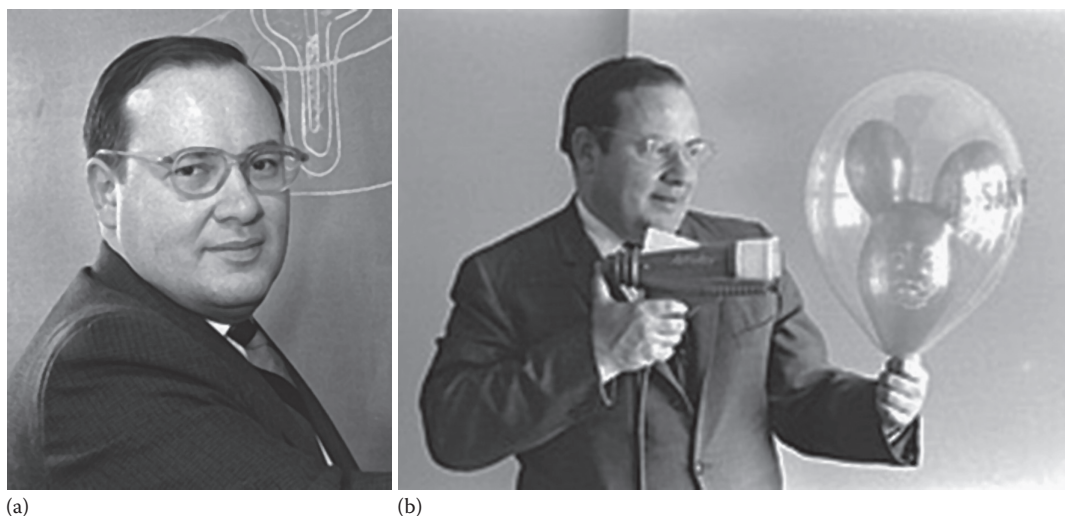


Figure S.23 (a,b) Arthur Leonard Schawlow (1921–1999), photograph by Kenneth Sherwin and Frans Alkemade. (Courtesy of Stanford University, Stanford, CA.)

Scheele, Carl Wilhelm (1742–1786)

[chemical, optics] Researcher from Sweden, chemist and pharmacologist. The work by Scheele published in 1777, describes the discoloration of paper coated with silver chloride when exposed to sun-light. Forefather of PHOTOGRAPHY. Scheele was also credited for the discovery of oxygen (joint discovery) and documented barium, manganese, molybdenum and tungsten next to several other chemical compounds. His discovery

of chlorine, derived from pyrolusite, lead to a systematic disinfection of water. The use of chlorine, next to bleaching (discovered also by Scheele) offered a SOLUTION to the eradication of the spread of several disease through drinking water (see [Figure S.24](#)).



Figure S.24 Carl Wilhelm Scheele (1742–1786).

Scherrer, Paul (1890–1969)

[atomic, nuclear] Swiss physicist working in diffraction in the beginning of the twentieth century. Scherrer's work included the mathematical description of the correlation between the PARTICLE configuration (i.e., shape), captured by the shape factor (K_{shape}), spacing of the scattering matrix ($\tau_{\text{crystalline}}$) and the angular distribution of the scatter of X-RAY radiation (θ) or Bragg ANGLE. The correlation is captured by Scherrer as a function of wavelength: $\tau_{\text{crystalline}} = K\lambda/\beta \cos \theta$, where β is the line-broadening of the probing ray at full-width half-maximum (FWHM). Particularly in X-ray diffraction used in crystallography the SHAPE FACTOR plays a crucial role and is usually smaller than 0.9. The boundary conditions for the Scherrer equation are nanometer range ($<100 \text{ nm}$). The experimental verification was defined in the DEBYE-SCHERRER METHOD, which has led to naming the diffraction distribution the DEBYE–SCHERRER EQUATION on occasion (see [Figure S.25](#)).

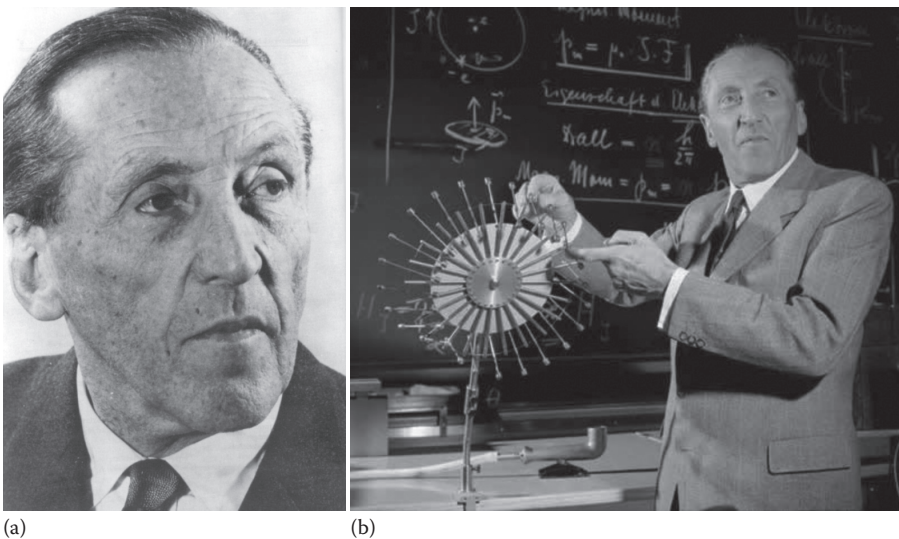


Figure S.25 (a,b) Paul Scherrer (1890–1969). (a—Courtesy of ETH-Bibliothek Zurich, Switzerland; Bildarchiv: Com_XS129–02; b—Courtesy of Paul Scherrer Institute, Villigen, Switzerland.)

Schiff, Leonard Isaac (1915–1971)

[nuclear] Researcher from Germany involved with the photo-nuclear aspects of X-RAY imaging and specifically BREMSSTRAHLUNG. More specifically Schiff described the spectrum of X-ray diffraction PHOTON scattering (see [Figure S.26](#)).



Figure S.26 Leonard Isaac Schiff (1915–1971).

Schlieren imaging

[fluid dynamics, imaging] Described by AUGUST TOEPLER (1836–1912) in 1894. Method based on the DISPERSION of LIGHT resulting from density gradient and discontinuities. On transillumination of a medium optical density differences can be revealed based on BIREFRINGENCE that are indicative of temperature effects or composition by means of special filtering. The feature recognition aspects are based on the Cauchy theorem. The IMAGE formation is based on the angular deflection of a light ray when passing through a region characterized by boundaries between regions of different refractive index, as defined by Schell's law. The localized strain in the medium resulting from temperature effects or from deformation resulting from an applied torque can in this manner be revealed by Schlieren imaging and can be used for quality control and testing for integrity (see [Figure S.27](#)).

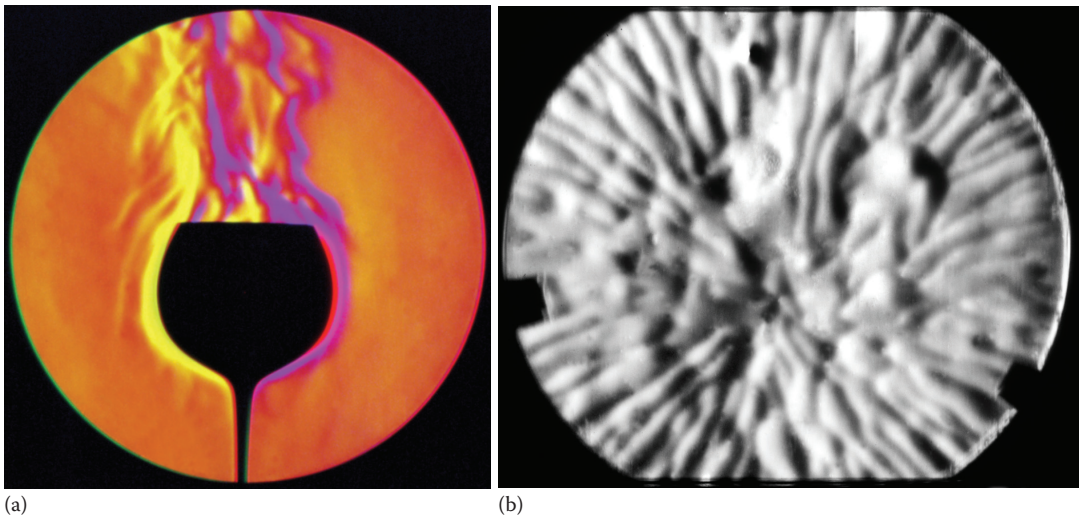


Figure S.27 (a) Schlieren imaging represented by the diffraction of light in the thermal convective flow above a heated object. (Courtesy of Andrew Davidhazy.) (b) Reflection "intensity" Schlieren for paraffin solution agitated by vibration.

Schlieren imaging for concentration

[biomedical, imaging, optics] Screening method for determination of molecular separation while applying the ULTRACENTRIFUGE principle. The general concept of LIGHT distortion resulting from density and associated index-of-refraction differences creates a diffraction pattern that illustrates the gradient in concentration of SOLUTE as a function of DISTANCE to the axis of rotation. The most obvious example of this is seen when adding sugar to water in a transparent beaker, showing the diffraction patterns (i.e., DISPERSION) in the SOLUTION as the solute migrates (see [Figure S.28](#)).

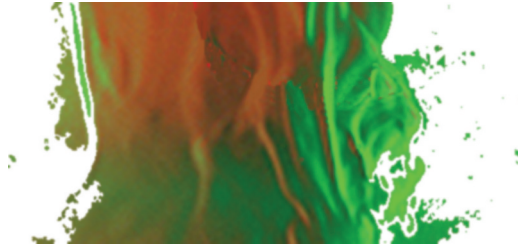


Figure S.28 Schlieren imaging for concentration, illustrating the dispersion in an inhomogeneous sugar solution.

Schmidt, Ernst Heinrich Wilhelm (1892–1975)

[fluid dynamics, general, thermodynamics] Engineer and physicist from Germany. Ernst Schmidt is best known for his contributions to the THERMODYNAMICS of flow as well as flow velocity profiling (see [Figure S.29](#)).



Figure S.29 Ernst Heinrich Wilhelm Schmidt (1892–1975). (Courtesy of Johanneum Lüneburg Informations system, Lüneburg, Germany.)

Schmidt number, ($Sc = \eta/\rho D_{AB}$)

[fluid dynamics] Dimensionless number defining the ratio of the momentum DIFFUSION to the molecular diffusion, where η is the viscosity, ρ the density and D_{AB} the diffusion coefficient for the constituents A and B . The number is named after the person who introduced the concept ERNST HEINRICH WILHELM SCHMIDT (1892–1975). The Schmidt number plays a role in identifying the EQUILIBRIUM STATE for OSMOTIC PRESSURE based on the transport of chemical species from the flow of BLOOD to the vascular (i.e., arterial/venous) WALL. For blood the Schmidt number is in the order $Sc \sim 10^5$.

Schottky, Walter Hermann (1886–1976)

[electronics, solid-state] German scientist who made several pivotal discoveries in solid-state ELECTRONICS and crystal structure. Schottky is also known for the invention of the screen-grid VACUUM tube. The screen-grid vacuum tube as introduced in 1915, is used to suppress the CATHODE ray emission flow of secondary electrons that are ejected from the ANODE on impact of the primary electrons and are hence a source of noise. Screen-grid vacuum tubes have a superior high frequency performance, with high gain. Walter Schottky is best known for the description of the solid-state ENERGY configuration that provided the tools for the development of the DIODE semiconductor. Of other theoretical description of the energy of a point-charge (with charge q) with respect to a flat metal surface: $E_{\text{charge}} = -q^2/16\pi\epsilon_{\text{EM}0}r$, where r represents the DISTANCE from the surface, and the permittivity of free space: $\epsilon_{\text{EM}0} = \epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ (see Figure S.30).

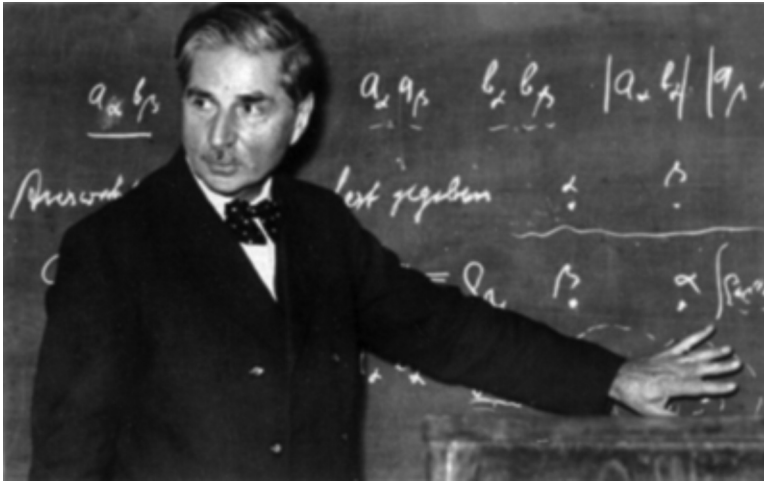


Figure S.30 Walter Hermann Schottky (1886–1976) in 1953. (Courtesy of Archiv der Max-Planck-Gesellschaft, Berlin-Dahlem, Germany.)

Schottky barrier

[electronics, solid-state] Metal-semiconductor ENERGY BARRIER for electron transport in a PN -JUNCTION configuration, often metal-silicon. The concept was introduced by WALTER HERMANN SCHOTTKY (1886–1976). The Schottky barrier may provide rectifying properties, converting alternating current in direct current, lending itself for the development of diodes. The Schottky barrier is defined based on the free-space SURFACE ENERGY when solving for a one-dimensional SCHRÖDINGER EQUATION for a single charged PARTICLE. The Schottky barrier representing the energy threshold that a charge needs to overcome to “conduct” through the barrier is defined as $E_{\text{Schottky}}(r) = b_{\text{Barrier}} - eEr - (q^2/4\pi\epsilon_r\epsilon_0r)$,

where $e = 1.60217657 \times 10^{-19}$ C is the electron charge (positive value), $E = V/d = F/q$ the applied electric field resulting from the externally applied POTENTIAL (V) spanning a DISTANCE d , b_{Barrier} the electric barrier height for the junction, often taken to be the work-function of the material (ϕ_{work}), the absolute permittivity of free space: $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ and the RELATIVE PERMITTIVITY with respect to the material ϵ_r . The Schottky barrier fits in the Schrödinger equation as an operator as $(d^2/dr^2)\psi(r) = (2m/\hbar)E_{\text{Schottky}}(r)\psi(r)$, with m the particle mass, $\hbar = h/2\pi = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ PLANCK'S CONSTANT, and $\psi(r)$ the wave-function. The forward voltage for the Schottky barrier is in the range of 0.15–0.45 V (in comparison to the normal p-n silicon DIODE of 0.6–1.7 V). Schottky barriers have a very fast response time. The metals used in the junction are for instance tungsten, chromium, molybdenum and platinum.

Schottky diode

[electronics, solid-state] DIODE based on the junction between a METAL and a semiconductor, thus creating an asymmetric ENERGY configuration. In comparison, the first PN-JUNCTION was created in 1939 as a forerunner to semiconductor ELECTRONICS.

Schottky effect

[electronics, solid-state] The application of an external electric field to a METAL in VACUUM will increase the current density of the electrons being released from the metallic surface when administering heat. Raising the temperature of metals can result in the emission of electrons, THERMIONIC EMISSION. Even though the vacuum forms an INSULATOR, the ENERGY BARRIER for electron release can still be approximated by the SCHOTTKY BARRIER.

Schrieffer, Howard Lawrence (1948–)

[computational, general] Scientist from the United States with a special philosophy on force and ENERGY, called the GRAND UNIFIED THEORY, building on the work of Howard Mason Georgi III (1947–) and SHELDON LEE GLASHOW (1932–) published in 1974 (see [Figure S.31](#)).



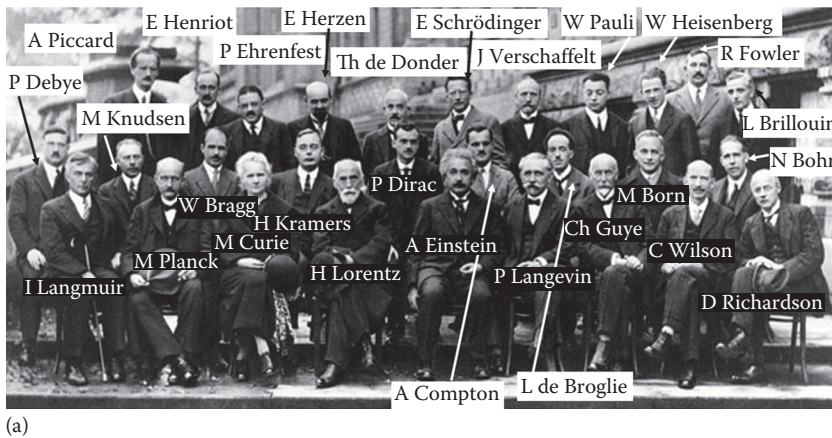
Figure S.31 Howard Lawrence Schrieffer (1948–).

Schriefer Unified Theory

[computational, general] Also referred to as a Grand Unified Theories. Unification of all theories, introduced by HOWARD LAWRENCE SCHRIEFER (1948–). In principle, the unified theories provides the basis for the formation of planets, satellites, next to continents on earths. The UNIFIED THEORY describes the operation of pulsars and how they are formed. It also provides a common GROUND for WAVE and PARTICLE theory. Furthermore, the GRAND UNIFIED THEORY postulates that time and temperature are inappropriate characteristics to be used in scientific descriptions due to their convoluted properties, as are their antecedents. It also provides a unique description for gravitational interaction. The Grand Unified Theories are for all means and purposes consistent with the Lorentz Law, AMPÈRE'S LAW and electromagnetic gauge invariance. The concept of unified theory is based on the unification of several electromagnetic theories by JAMES CLERK MAXWELL (1831–1879). The concept is based on the fact that the strong, weak and ELECTROMAGNETIC THEORY of nuclear forces do not share the inverse square law that applies to GRAVITATION and the strict formulation of conservation of charges. The “unified” process makes an attempt to bridge the differences between electromagnetic theory and gravitational theory. The unified theories incorporate a broader range of symmetries, extending beyond the coordinate invariance principles of ALBERT EINSTEIN (1879–1955), incorporating the electromagnetic gauge invariance. In the unified theory the concept of “symmetry” loses significance after developing the gauge- and gravitational forces in a series beyond the second iteration, symmetry is lost/broken. The unified theory introduced by Schriefer (see GRAND UNIFIED THEORIES).

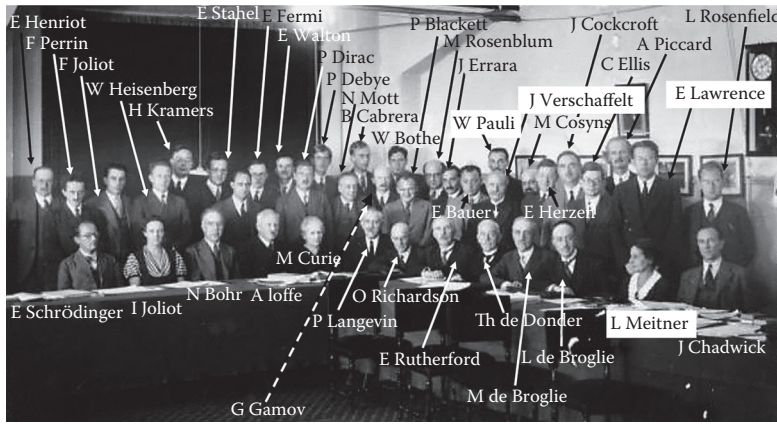
Schrödinger, Erwin Rudolf Josef Alexander (1887–1961)

[atomic, computational, energy, general, mechanics, nuclear, quantum] Physicist from Austria who, inspired by the principle of the DE BROGLIE WAVE, introduced the relativistic concept (determined by PROBABILITY rather than cause-and-effect) of wave-mechanics; the SCHRÖDINGER EQUATION OF MOTION, or SCHRÖDINGER WAVE EQUATION (see Figure S.32).



(a)

Figure S.32 Erwin Rudolf Josef Alexander Schrödinger (1887–1961) at the various Solvay conferences: (a) 1927. (Continued)



(b)



(c)

Figure 5.32 (Continued) Erwin Rudolf Josef Alexander Schrödinger (1887–1961) at the various Solvay conferences: (b) 1933 and (c) Erwin Schrödinger in 1933.

Schrödinger equation

[thermodynamics] See **SCHRÖDINGER EQUATION OF MOTION**.

Schrödinger equation of motion

[computational, nuclear, thermodynamics] Experiments performed in the early twentieth century gave rise to the notion that all particles in MOTION exhibit wavelike characteristics. The most formidable evidence came from the electron orbit model described by PRINCE LOUIS DE BROGLIE (1892–1987), requiring a standing WAVE to satisfy the filling of the various ORBITS. A PARTICLE moving in one dimension: x – direction, with mass: m , and with inherent kinetic ENERGY E and under a resident potential energy V , the SCHRÖDINGER WAVE EQUATION is defined as $(\partial^2 \Psi / \partial^2 x) + (8\pi^2 m / b^2)(E - V)\Psi = 0$, where $b = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$ PLANCK'S CONSTANT, and Ψ is the wave-function for the particle in motion describing the PROBABILITY distribution for have a specific configuration at a specific location. The SCHRÖDINGER EQUATION defines the kinetic energy combined with the potential (also known as the Hamiltonian: H operator) of the wave function Ψ , which encompasses all the dynamic statistics about a system. The function Ψ is a SCALAR function with complex values: $(E - V)\Psi = H\Psi = -(i\hbar/2\pi)(\partial\Psi/\partial t) = (-\hbar^2/8m)\nabla^2\Psi + V(0, x)\Psi$, where the Laplace operator represents the location derivative in second order: $\nabla^2 = (\partial^2/\partial x^2) + (\partial^2/\partial y^2) + (\partial^2/\partial z^2) = (\partial^2/\partial \theta^2) + (\partial^2/\partial r^2) + (\partial^2/\partial \phi^2)$. For the time-independent Schrödinger case, energy is derived using the operator $-i\hbar\partial/2\pi\partial t$, with the kinetic energy defined by the square of the momentum operator: $i\hbar\nabla^2/8m$. Using the boundary condition for the potential at $t = 0$: $V(0, x)$ and applying all the suitable boundary conditions, solving the Schrödinger differential equation generates a wave function Ψ which comprises all the characteristics and properties of the system. Alternatively, the Schrödinger equation can be expressed using the momentum of the particle, defined by $\hat{P}\Psi(r, t) = -(i\hbar/2\pi)\nabla^2\Psi(r, t)$, where the energy is linked to the momentum as $E = \hat{P}^2/2m$; where $\hat{P}$ defines the Momentum operator; $\hat{P} = m\vec{v}$, for a mass traveling with velocity $\vec{v}$. There is a remarkable similarity with the energetic format of the Hamiltonian equation, describing the total energy ($KE + U = E$, the sum of kinetic [$KE = (1/2)mv^2 = p^2/2m$] and potential [U] energy) as $(1/2m)p^2 + U = E$ described by WILLIAM HAMILTON (1805–1865). This concept was adapted by ERWIN

SCHRÖDINGER (1887–1961) into a differential equation; the wave equation. The EQUATIONS OF MOTION in Hamiltonian space are $\dot{p}_j = -(\partial H / \partial q_j)$ and $\dot{q}_j = +(\partial H / \partial p_j)$, with $H(p, q) = \sqrt{(m^2 + p^2)}$ the Hamiltonian function of energy for a particle. Also known as the Schrödinger Equation (see Figure S.33).

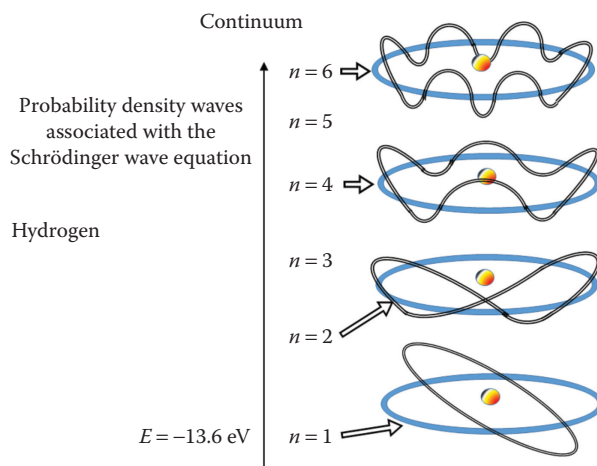


Figure S.33 Schrödinger motion.

Schrödinger Wave Equation

[computational, general, nuclear, thermodynamics] Mathematical description of the PROBABILITY of a phenomenon being at a certain place in a certain timeframe, expressed as $(1/2m)(i\hbar)^2 \{ (d^2\Psi/dx^2) + (d^2\Psi/dy^2) + (d^2\Psi/dz^2) \} + U\Psi = -E\Psi$, with E is the total ENERGY of the phenomenon, (x, y, z) three-dimensional CARTESIAN COORDINATES, Ψ the WAVE function of the phenomenon, U is the potential energy, m the mass of the object, $\hbar = h/2\pi$, where $h = 4.13567 \times 10^{-15}$ eVs the Planck constant, or referred to by MAX KARL ERNST LUDWIG PLANCK (1858–1947) as “the QUANTUM of action.”

Schrödinger's cat

[atomic, computational, energy, general, mechanics, nuclear, quantum] Paradox describing the fact that in quantum PHYSICS and WAVE MECHANICS all events are described in PROBABILITY of state. An event is not certain unless it is observed. The PARABOLA with the cat was introduced by ERWIN SCHRÖDINGER (1887–1961) in 1935. The interpretation of the Copenhagen description of QUANTUM MECHANICS left many questions in the interpretation of how reality and probability are not compatible in quantum physics. The cat anecdote describes how one event may control the outcome of another event without a definite cause and effect. The cat is supposedly locked in a box that contains a mechanism controlled by a nuclear disintegration. The mechanism is initiated by the DECAY of a RADIOACTIVE ISOTOPE such as uranium that will result in the registration by a GEIGER COUNTER which in turn engages a hammer that shatters a GLASS jar containing the poisonous hydrocyanic ACID. In case the uranium decays the cat will be dead after inspection of the cage when 1 h has lapsed, in case the ISOTOPE did not decay the cat will be alive. In QUANTUM mechanical terms the cat is bot

alive and dead at the same time, whereas in classical terms the cat will be either alive or dead based on a more predictable cause–effect relationship, such as being confined with a mouse for 1 h (see [Figure S.34](#)).

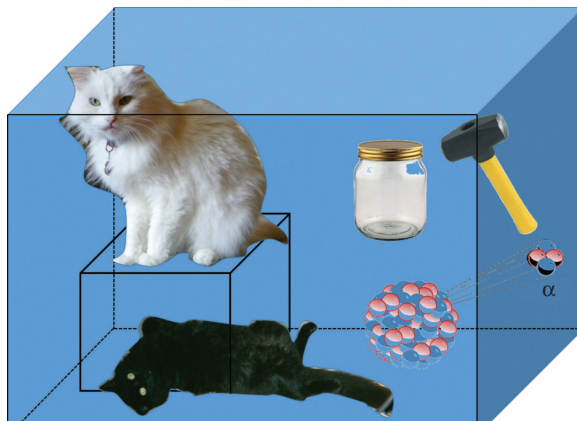


Figure S.34 Concept of probability explained by Schrödinger's cat; which decay event will make the hammer strike the glass jar which will release the poisonous gas, there will be a probability associated with this occurrence.

Schuster, Arthur, Sir (1851–1934)

[astrophysics/astronomy, computational, optics] German physicist who provided critical steps in the development of a computational mechanism to describe the diffuse propagation of LIGHT through turbid media. Schuster worked on X-RAY imaging and OPTICS as well as SPECTROSCOPY. The works of KARL SCHWARZSCHILD (1873–1916) and SUBRAHMANYAN CHANDRASEKHAR (1910–1995) were inspired by his efforts on the mathematical description of the propagation of light through an attenuating and scattering medium. The culmination of Dr. Schuster's work on optics is found in the EQUATION OF RADIATIVE TRANSFER, pertaining to both astronomy and BIOMEDICAL OPTICS. Schuster also provided elementary contributions to the discovery of the electron. In this work he provided a mechanism to derive the ratio of charge to mass for CATHODE RAYS, discriminating protons from electrons, later formalized by ERNEST RUTHERFORD (1871–1937) (see [Figure S.35](#)).



Figure S.35 Sir Arthur Schuster (1851–1934) in 1912, by William Orpen.

Schwarzschild, Karl (1873–1916)

[astronomy, biomedical, computational, general, optics] Astrophysicist and mathematician from the Prussian Empire (Germany). Karl Schwarzschild worked parallel with SIR FRANZ ARTHUR FRIEDRICH SCHUSTER (1851–1934) on the theoretical description of RADIATIVE TRANSFER with respect to the RADIATION emitted from stars traversing a UNIVERSE filled with dust, gasses and planets, published in 1905 and 1906, respectively. Karl Schwarzschild used photographic recordings for QUANTIFICATION of the brightness of stars and deriving the optical path for reaching EARTH. The HEAT TRANSFER and emission of radiation from stars and the interaction with cosmic material forms the basis of BIOMEDICAL OPTICS in the EQUATION OF RADIATIVE TRANSFER, also found as Radiative Transfer Equation (*also see* BIOMEDICAL OPTICS) (see [Figure S.36](#)).



Figure S.36 Karl Schwarzschild (1873–1916).

Scuba gear

[biomedical, fluid dynamics] Apparatus used for deep-sea diving that will provide an oxygen supply under controlled circumstances. The equipment concept was described by the French author Jules Verne (1828–1905) in “Vingt Mille Lieues sous les mers,” 1870 (*Twenty Thousand Leagues Under the Sea*). The Jules Verne concept was based on the explorations by earlier engineers and inventors such as the British engineer, John Smeaton, who invented the AIR pump in 1771. Another self-sustaining breathing device was constructed in 1825 by the English inventor William James using a copper helmet attached to a vessel (belt) filled with compressed air. Another Englishman, Henry Fleuss, conceived a recirculation device infusing pure Oxygen into the respiratory system in 1876, which made him fall victim to the fact that pure Oxygen deregulates the human breathing mechanism. The inhalation of the pure oxygen killed him as a result of the biofeedback deregulation. The human RESPIRATION is regulated by chemical sensors that respond to dissolved Carbon Dioxide; the reaction of WATER (H_2O) with CO_2 forms H_2CO_3 (carbonic ACID), which has an inherent acidity. The lack of CO_2 makes the autonomic nervous system shut down the desire to inhale fresh air. In 1873 an entirely new approach resulted from the work of Benoît Rouquayrol and Auguste Denayrouze resulting in a rigid diving suit with a regular air supply. The concept was made of METAL and weighed approximately 100 kg. Further improvements resulted from the efforts by engineer and sensationalist Harry Houdini in the year 1921 (born Ehrich Weiss 1874–1926 in Budapest, Hungary). The first metallic caissons used for underwater exploration were cumbersome and did not allow free movement. These constructions used an air-hose that lead to the surface of the water requiring manual labor to PUMP fresh air to the diver. In 1943 the French naval officer Jacques-Yves Cousteau (1910–1997) and his fellow inventor and engineer Émile Gagnan (1900–1979) made a breakthrough contribution to the work of several predecessors and contemporaries in the introduction of the compressed air breathing devices for

extended underwater exploration: the “Aqualung.” Jacques Cousteau is mostly known for his oceanographic explorations, documentaries and nature conservation efforts pertaining to the marine flora and fauna (see Figure S.37).

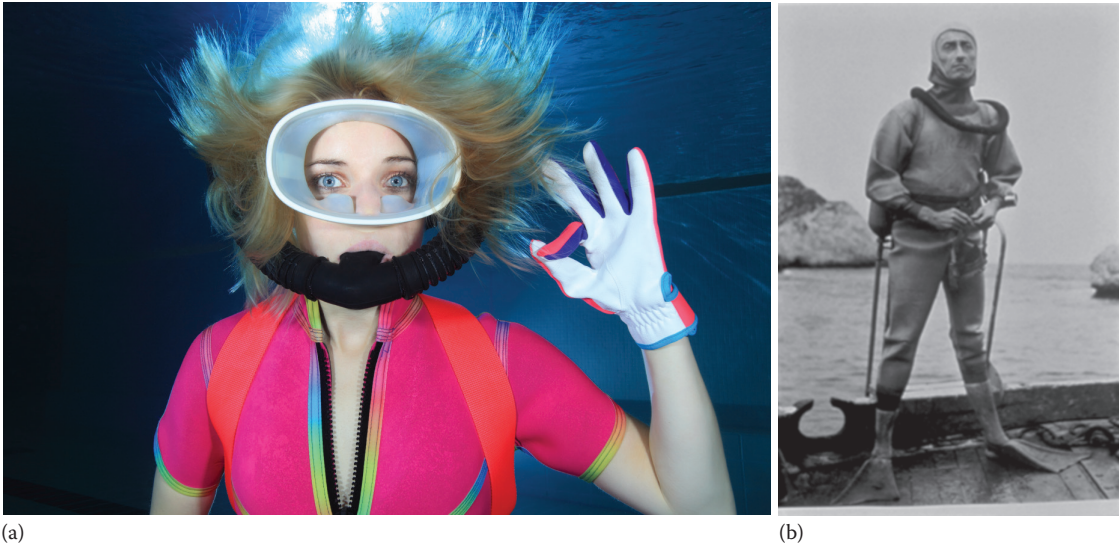


Figure S.37 (a) Diver in scuba gear and (b) Jacques-Yves Cousteau (1910–1997). (Courtesy of the Cousteau Society, Paris, France.)

Second

[general] Measurement of time; Definition: SI: based on the earth’s revolution in 24 h, originally introduced as the fraction of the average length of a day as $1/60 * 1/60 * 1/24 * \text{mean duration of a day averaged over a year}$. The current definition of the second is the duration of 9,192,631,770 oscillations of the Cesium-133 ATOM between the lowest two ENERGY states, accurate to 1 in 10^{13} . This standard is referred to as the “ATOMIC CLOCK,” introduced in 1967 (see Figure S.38).



Figure S.38 The second on an analog time keeping piece.

Second law

[thermodynamics] See SECOND LAW OF THERMODYNAMICS.

Second law, Kelvin–Planck’s statement

[thermodynamics] “It is unachievable to build a fully functional ENGINE that is solely based on the extraction of heat from a reservoir at a single temperature while converting all the acquired heat perfectly into MECHANICAL ENERGY.” Introduced by LORD KELVIN (1824–1907).

Second law of Faraday

[Atomic, general, nuclear, quantum, thermodynamics] “The total mass of SOLUTE liberated from a SOLUTION is proportional to the total quantity of charge traversing through a circuit that has the solution as the integral part of the sole current loop” (see FARADAY, SECOND LAW OF).

Second law of thermodynamics

[general] “It is unachievable to build a fully functional ENGINE that is solely based on the extraction of heat from a reservoir at a single temperature while converting all the acquired heat perfectly into MECHANICAL ENERGY.” The change in ENTROPY (S) of all systems involved in a process will always be positive: $\Delta S \geq 0$, noting that for an ideal (theoretical case) reversible process the entropy will remain unchanged (see THERMODYNAMICS, SECOND LAW OF).

Second law of thermodynamics, Carathéodory’s statement of the

[computational, thermodynamics] Axiomatic expression by the Greek mathematician CONSTANTINE CARATHÉODORY (1873–1950) with respect to the subsystems with equal or less parameters and equal or less data-points/coordinates expressed in 1910 pertaining to the SECOND LAW OF THERMODYNAMICS, centered around PFAFFIAN differential equations eliminating the need for imaginary engines to compensate for deviations resulting from the improbability of the “perpetuum mobile,” based on geometric formulation. The basis of the Carathéodory’s theorem is the fact that “In the proximity of any EQUILIBRIUM STATE of a system (composed of any number of thermodynamic coordinates, and valid in any geometric configurations), there will be states that cannot be achieved through reversible adiabatic processes.”

Second law of thermodynamics, Clausius formulation

[general, thermodynamics] Expression of the lack of 100% efficiency in ENERGY conversion, similar to the SECOND LAW, KELVIN–PLANCK’S STATEMENT. RUDOLF JULIUS EMANUEL CLAUSIUS (1822–1888) formulated that a refrigeration system cannot transfer heat from the cold to the hot reservoir without the use of an external source and hence requires external energy.

Second order differential equations

[computational] Differential equations that include derivatives up to the second order, generally either time or location specific.

S

Second order phase transition

[computational, thermodynamics] At the critical point, where the critical temperature and critical pressure are reached, the PHASE TRANSITION between LIQUID and VAPOR anomalous behavior is observed in the thermodynamic parameters such as SPECIFIC HEAT and compressibility due to the fact that the density of the liquid and vapor phase at the raised temperature and pressure has reached equilibrium, they are

identical. At the critical point the correlation length associated with the physical phenomena has exceeded the standard length (e.g., intermolecular DISTANCE) for the normal phase transition (see Figure S.39).

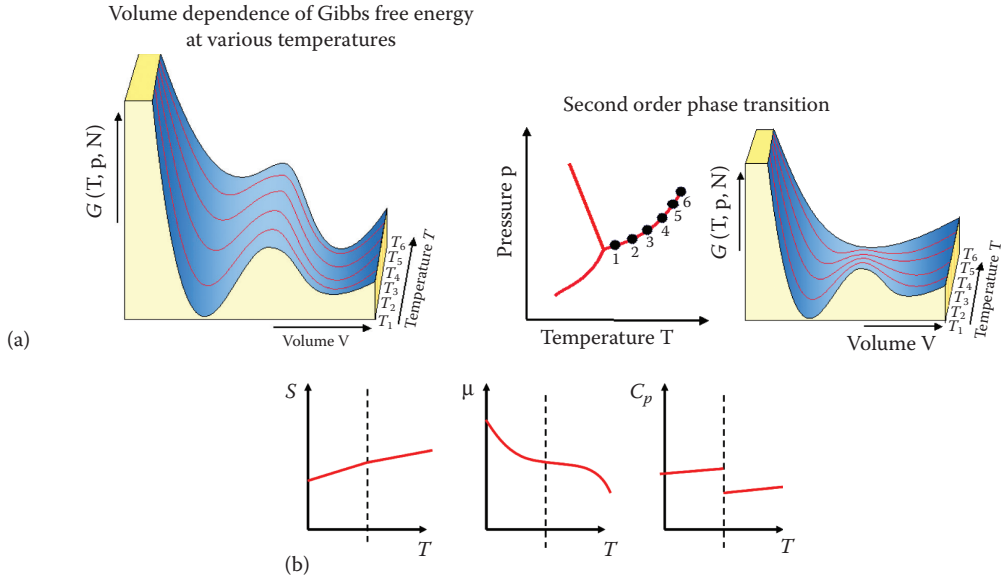


Figure S.39 (a,b) Diagram outlining the configuration of a second-order phase transition.

Second-generation of matter

[atom, high-energy, nuclear, solid-state] ELEMENTARY PARTICLES discovered in a certain order, as outlined under Quarks. Quarks (CHARM, strangeness); Leptons (MUON, μ -neutrino).

Sediment equilibrium

[biomedical, chemical, mechanics] Mechanism of action used to determine molecular weight of the SOLUTE under ULTRACENTRIFUGE treatment. At the point of equilibrium between DIFFUSION and sedimentation the concentration $[C]$ will depend on the DISTANCE (r) to the axis of rotation: $[C_r]$ as a function of ANGULAR VELOCITY ω . The MOLECULAR WEIGHT (M) distribution under ABSOLUTE TEMPERATURE (T) and rotational angular velocity: ω , with the assigned partial specific volume of the solute $\bar{V}$ expressed as $M(r) = RT \ln([C_r]/[C_n]) / [(1 - \rho \bar{V}) \omega^2 (r_2^2 - r_1^2)]$, where R is the UNIVERSAL GAS CONSTANT, and ρ is the SOLVENT density based on the dissolved constituent. Under conditions of very large molecular weight (i.e., MACROMOLECULES) the sedimentation time duration will reach equilibrium after an extensive period of slow rotational centrifuge revolution, and can take in excess of 24 h in certain cases.

Sediment equilibrium in a density gradient

[biomedical, chemical, mechanics] Mechanism of action used to determine molecular weight of a binary solutions under ULTRACENTRIFUGE treatment. Solutions where the SOLUTE with low MOLECULAR WEIGHT (M) has a close to equivalent weight to the SOLVENT it will tend to segregate as a function of DISTANCE to the rotational axis (r), which can be quantified when equilibrium is established. Due to the equivalence the solute will be buoyant and segregation will depend on the density gradient in the medium: $d\rho/dr$, where ρ is the solvent density based on the dissolved constituent, with a band-width per concentration that is identified by the one-dimensional standard deviation σ . The molecular weight (M) distribution under ABSOLUTE TEMPERATURE (T) and rotational ANGULAR VELOCITY: ω , with the assigned partial specific volume of the solute $\bar{V}$ expressed as $M = RT / [\bar{V} \omega^2 (d\rho/dr) \sigma^2 r]$, where R is the UNIVERSAL GAS CONSTANT.

Sedimentation velocity

[biomedical, chemical, mechanics] Used in the process describing the rate of change expressed by the sedimentation coefficient: $\zeta = (dr/dt)/\omega^2 r$, with ρ the SOLVENT density based on the dissolved constituent, the DISTANCE to the axis of rotation r and rotational ANGULAR VELOCITY ω , and dr/dt the SOLUTE sedimentation velocity. This mechanism of action is used to determine molecular weight of the solute under ULTRA-CENTRIFUGE treatment. The MOLECULAR WEIGHT M of the solute follows from $M = RT\zeta/(1 - \bar{V}\rho)$, where R is the UNIVERSAL GAS CONSTANT, ρ is the solvent density and D is the DIFFUSION coefficient.

Seebeck, Thomas Johann (1770–1831)

[energy, thermodynamics] Scientist from the Prussian Empire/Estonia (Russia?). Thomas Seebeck discovered in 1821 that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the junctions. Additional work by Thomas Seebeck is in the precursor to the discovery of PHOTOGRAPHY. Seebeck described the change in appearance of silver-chloride under the influence of LIGHT in 1810 (see LOUIS-JACQUES-MANDÉ DAGUERRE [1771–1851]) (see Figure S.40).



Figure S.40 Thomas Johann Seebeck (1770–1831). (Courtesy of Hans Wahl, Anton Kippenberg: Goethe und seine Welt, Insel-Verlag, Leipzig 1932 S.204.)

S

Seebeck effect

[electromagnetism, thermodynamics] The conversion of temperature differences directly into ELECTRICITY. The voltage (electromotive force: EMF: V_{EMF}) produced between two junctions is proportional to the temperature difference between those two point: $V_{\text{EMF}} = S_{\text{Seebeck}} (T_{\text{high}} - T_{\text{low}})$, where the coefficient S_{Seebeck} represents the influence between the two media in contact on the voltage difference, which relates to the PELTIER COEFFICIENT (Π_i) as $TS_{\text{Seebeck}} = \Pi_i$. The EMF produces a current which can be registered by a GALVANOMETER. This effect was described in 1826 by THOMAS SEEBECK (1770–1831) (also see PELTIER EFFECT).

Segrè, Emilio Gino (1905–1989)

[nuclear] Physicist from Italy. Segrè received the Nobel Prize in Physics in 1959 for his contributions and discoveries in PARTICLE physics, including the discovery of the ELEMENTS technetium and astatine, as well as his work on the antiproton (subatomic antiparticle) with Owen Chamberlain (1920–2006) and Clyde Wiegand (1915–1996) in 1955 (see Figure S.41).



Figure S.41 Emilio Gino Segrè (1905–1989).

Seismic

[acoustics, general, geophysics, mechanics] Physical phenomena associated with shallow earthquakes causing surface faulting (i.e., instability or mode of **VIBRATION**) or the damped oscillatory **GROUND** movements with destructive effects resulting from a major **EARTHQUAKE**. Seismic models rely on finite **ELEMENT** reconstructive structural and stratigraphic representation. Here stratigraphy pertains to the study of the composition, relative ages with associated historical value, as well as the distribution of layers of sedimentary rock (i.e., strata), combined with the interpretation of strata to uncover the Earth's geological history (see [Figure S.42](#)).

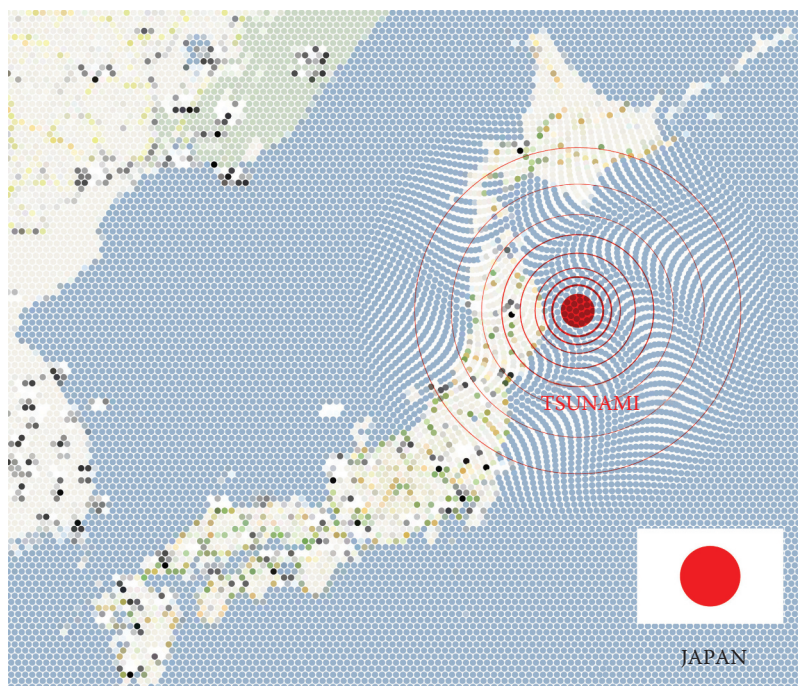


Figure S.42 Graphical representation of the seismic concept.

Seismic acoustic imaging

[acoustics] Large-scale imaging of predominantly geological and aquatic features by means of artificially induced seismic ACTIVITY, for example, explosions or impact collisions (either using a heavy weight or compressed AIR). The induced pressure wave resulting from the impulse source, acts as an imaging source. Using the obtained FREQUENCY SPECTRUM assumptions can be made about the elastic modulus distribution of the volume under interrogation, which can be used to define the WAVE-EQUATION responses and hence use time-of-flight of echoes for imaging purposes, including compensations for SCATTERING resulting from inhomogeneities and discontinuities. This type of imaging is used in the localization of water sources or OIL pockets (e.g., SEISMIC prospecting) (see [Figure S.43](#)).

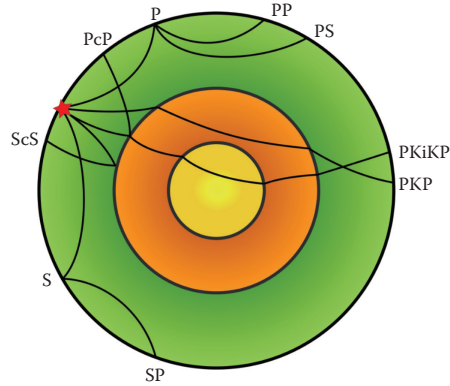


Figure S.43 Seismic imaging diagram, based on S-wave and P-wave; Cross section of Earth with different seismic paths with reflection and refraction on the layers. Mechanism using two or more locations where seismic activity is recorded to triangulate the source of the seismic activity, which could be man-made such as underground nuclear explosions.

Seismic wave

[acoustics, general, geophysics, mechanics] Deformation WAVE resulting from natural forces such as volcanic eruptions, METEOR impacts, tsunamis, earthquakes, next to man-made impulse forces such as explosions. Underground nuclear tests are easily identified at great DISTANCE based on seismic wave propagation, specifically using triangulation from several detection bases (see [Figure S.44](#)).

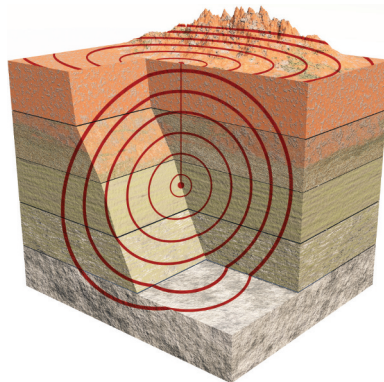


Figure S.44 Diagram of Seismic wave propagation.

Seismic wave, dissipative effects

[acoustics, geophysics, mechanics] The propagation of seismic waves resulting from earthquakes and other natural (e.g., volcanic eruptions) and man-made phenomena (e.g., explosions, fracking) is a perturbation that is subject to a broad frequency spectrum, and additionally the attenuation parameters with respect to the damped waves are a function of the frequency and local geological material configuration (e.g., visco-elastic behavior). The attenuation is generally described by an elastic—ENERGY dissipation factor defined by the concept “ q ,” where $q = \Delta E / 2\pi E_{\max}$, where $E_{\max}$ represents the maximum energy contained in the SEISMIC event and ΔE is the loss of INTERNAL ENERGY during one cycle of the mechanical/acoustic perturbation. The full range of frequencies associated with mechanical oscillations of the EARTH’S CRUST can be described by extending from 0.0005 Hz (period greater than 2000 s, ~35 min) to approximately 100 Hz (period 0.01 s). The other identifier related to the seismic dissipative effects is the QUALITY FACTOR: $Q \equiv 1/q$. The attenuation as a function of FREQUENCY ($\nu = \omega/2\pi$; ω the ANGULAR FREQUENCY) can generally approximated by a POWER LAW, providing the equivalence: $q \propto \omega^{-\alpha_{\text{acc}}}$, where generally $\alpha_{\text{acc}} < 0.5$ is the model factor for the phenomenon. This indicates that higher mechanical displacement frequencies will DECAY faster than low frequency patterns. The anelastic and elastic properties of the earth’s crust are a function of the local geological formations and configurations. Geological pattern may be rock formations, clay and water; all of which may be function of depth. These differences in related and associated Young’s Moduli will result in dispersive effects. The frequency dependency is further complicated by the fact that the seismic waves can be composed of spheroidal modes (large scale) expressed in propagating SURFACE WAVES, or normal mode standing waves. When these modes reach discontinuities at an ANGLE the WAVE will refract, similar to optical electromagnetic waves. The FREQUENCY SPECTRUM of the attenuation can be represented in “frequency modes,” or “angular (frequency) modes” (angular modes is the preferred term). The attenuation as a function of angular mode can be written with local radial shear and bulk moduli: $\mu_{\text{shear},0}$ respectively $K_{\text{bulk},0}$; next to the radial attenuation for shear, respectively bulk: $q_{\mu,\text{shear},0}$ respectively $q_{K,\text{bulk},0}$: $q = \int_0^R (\kappa_0 q_{K,\text{bulk},0} K_{\kappa} + \mu_{\text{shear},0} q_{\mu,\text{shear},0} K_{\mu_{\text{shear}}}) dr$, where R is the earth’s radius and K_{κ} respectively $K_{\mu_{\text{shear}}}$ are the bulk and shear kernels, the mathematical vector ELEMENTS that provide an indication of discontinuity or deviation from a “smooth” pattern. For long period seismic waves, greater than 300 s, the model factor decreases and eventually becomes negative. The DISPERSION between waves with different frequencies can be captured by the wave propagation velocity (ν_{ω_i}) in the form: $\nu_{\omega_2} / \nu_{\omega_1} = 1 + (q/\pi) \ln(\omega_2/\omega_1)$ in case the model factor is zero ($\alpha_{\text{acc}} = 0$), which describes phenomena occurring in the lower mantle. For the upper mantle the model factor is generally nonzero and the dispersion becomes: $\nu_{\omega_2} / \nu_{\omega_1} = 1 + [q(\omega_1)/2] \cot(\alpha_{\text{acc}}\pi/2) [1 - (\omega_2/\omega_1)^{\alpha_{\text{acc}}}]$.

Seismology

[energy, fluid dynamics, general, geophysics, mechanics] Field of PHYSICS dealing with physical phenomena in the solid part of the PLANET considered to be behaving as a LIQUID. The process of earthquakes and WAVE propagation (e.g., SEISMIC WAVES) falls under seismology. Additionally the sonic probing of the planets crust is also part of seismology, in this case small explosions generate a sonic (i.e., acoustic) wave that can be used to IMAGE the structural composition of the solid surface layer of the planet in a manner similar to ULTRASONIC IMAGING in biology and MEDICINE. The formation and propagation of TSUNAMI waves in water beds also falls under seismology.

Seismometer

[acoustics, general, geophysics, mechanics] Device used to register oscillations in the EARTH'S CRUST. Specific applications are in earthquakes, using the Richter scale as an indicator of MAGNITUDE on a logarithmic basis (see [Figure S.45](#)).

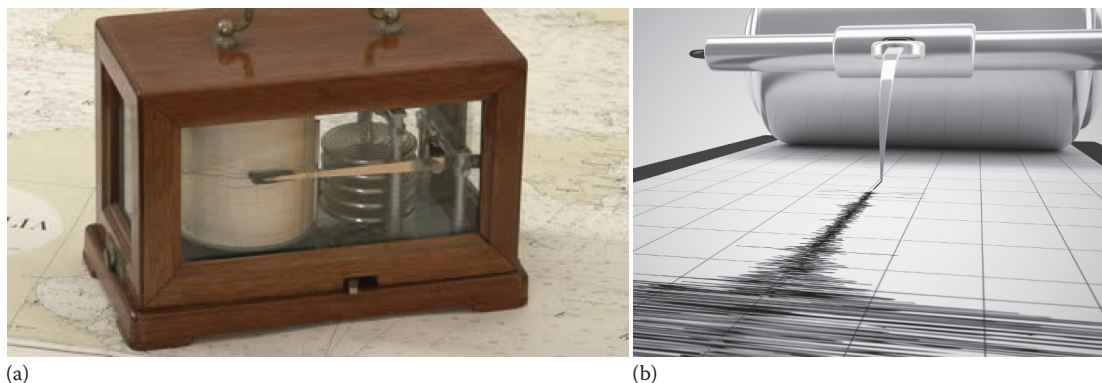


Figure S.45 (a,b) Seismometer.

Selectin

[biomedical, chemical] Molecular chains that provide the ADHESION of the surface of the membrane of leukocytes (their host environment) and endothelial cells that have been activated for construction in vascular assembly and healing. The main binding attraction of the selectin (glycol-) protein is to carbohydrates. Selectins form a specific class in biology providing cell-to-cell interaction. This interaction can be divided in four types of receptors: CADHERINS, selectins, INTEGRINS and IMMUNOGLOBULIN SUPERFAMILY (*see* CADHERINS).

Selection rule and

[atomic, computational, nuclear, quantum] (*see also* angular momentum conservation, parity conservation) Quantum-mechanical rules setting the stage for ENERGY balance pertaining to CONSERVATION OF ANGULAR MOMENTUM and conservation of PARITY in electron orbital configuration. The selection rules form the guide-book to electron transitions, as well as the PROBABILITY of each potential transition. The notation and rules are slightly different between atomic transitions and those for molecular excitation and DECAY. Two phenomena stand out in the electron transition: the PASCHEN BACK EFFECT and the ZEEMAN EFFECT. The Zeeman effect is generally determined by the selection rules, with specific selection rules applied to the NORMAL ZEEMAN EFFECT and the ANOMALOUS ZEEMAN EFFECT. Most orbital transitions are forbidden by selection rules. The standing order of selection rules are as follows. The value of the magnetic moment QUANTUM NUMBER ℓ changes in unity: $\Delta\ell = \pm 1$ and the MAGNETIC moment remains unchanged or changes by unity: $\Delta m = 0, \pm 1$. For the normal Zeeman effect: $\Delta L = 0, \pm 1$, however there is no ALLOWED TRANSITION that involves $L = 0$ to $L = 0$; $\Delta M_L = 0, \pm 1$; $\Delta S = 0$; and $\Delta M_S = 0$, where L represents the angular momentum of the ORBITAL ANGULAR MOMENTUM of the electron, S represents the ELECTRON SPIN (which cannot change, since that would mean a reversal of rotation direction), J represents the TOTAL ANGULAR MOMENTUM quantum number (a transition that involves $J = 0$ to $J = 0$ is also not allowed), respectively M_L the magnetic moment and M_S the SPIN moment, and in reference n is the primary quantum number. Some of the rules find their origin in the RUSSELL–SAUNDERS APPROXIMATION OF ELECTRON COUPLING.

Selectively permeable

[biomedical] The restrictive transport of molecules and particles through the membrane of CELL based on charge polarity and/or shape and size (more specifically pertaining to MOLECULAR WEIGHT or macroscopically to the chemical “nanoparticle”).

Self-avoiding walk

[computational] In computational methods the SOLUTION is derived for a process involving each point in the process only once, meaning that the path in n -dimensional space never intersects in the steps in the mathematical algorithm. This process resembles a very tightly organized maze or LATTICE. The process is used in simulation techniques, more prevalent in for-instance Monte-Carlo simulations and Java programming. Expressed in matrix format this would entail a one-sided matrix, specifically if the matrix would be symmetric. For an $n \times m$ matrix the computational process can migrate from one diagonal to the other diagonal. When numerically moving in the positive direction there will be a total of $(n + m/n, m)$ different potential paths available (see Figure S.46).

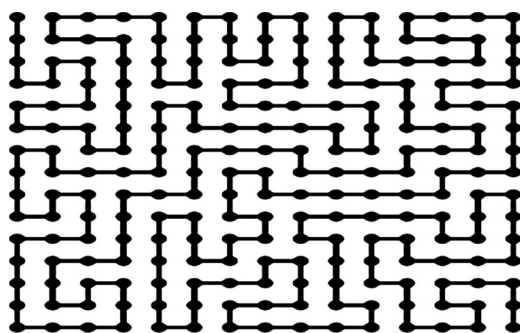


Figure S.46 Diagram illustrating the concept of Self-avoiding walk.

Self-consistent field

[atomic, computational] Method used to calculate the three-dimensional potential distribution for an electron cloud also referred to as the Hartree–Fock method.

Self-energy, coulomb

[nuclear] In the computation of the Coulomb ENERGY (E_{Coulomb}) with respect to the electron potentials ($V(\vec{r})$) of an electron (e) distribution with charge density ($\rho(\vec{r})$) over space ($\vec{r}$) the total Coulomb energy representing the total energy between the protons of the NUCLEUS is given by $E_{\text{Coulomb}} = (1/2)e \int_0^\infty \rho(\vec{r}) V(\vec{r}) 4\pi r^2 dr = 1/8\pi \int_0^\infty (\epsilon(\vec{r}))^2 4\pi r^2 dr$, where $\epsilon(\vec{r})$ is the local electric field. The SOLUTION is proportional to r^4 inside the nucleus and r^{-2} outside. The self-energy is the Coulomb energy of a single isolated PROTON with its WAVE-function spread-out over the entire volume of the nucleus.

Self-excited vibration

[computational, dynamics, fluid dynamics, general, mechanics] In contrast to forced vibrations the driving mechanism comes from within the system, maintaining the MOTION with INTERNAL ENERGY. The OSCILLATION frequency is thus not linked to a driving oscillation frequency. The phenomenon is described by the EQUATION OF MOTION ($m(d^2x/dt^2) + c(dx/dt) + kx = 0$, where m is the mass of the oscillating object, x the displacement, k the spring constant, $d^2x/dt^2 = a$ the acceleration, and $c = \text{const}$ representing the

predictable pattern of temporal changes in boundary conditions, including density, for instance COMPLIANCE) as a homogeneous SOLUTION that however is unstable. Examples of self-excited vibration are the hysteretic whirl, and pulsatile longitudinal loading. Another example is found in the FLUID motion of an enclosed rotor or rotor-axis.

Self-induced electromotive force

[general] The response in induced electro-motive-force voltage resulting from a change in a CURRENT (I) in a circuit that has a coil as a component as defined by LENZ'S LAW. The induced rate of change in the MAGNETIC FIELD resulting from the change in current inflicts its own emf. The self-induced EMF will be opposite the naturally occurring EMF resulting from external sources: $\varepsilon_{\text{EMF}} = -L_{\text{ind}}(dI/dt)$, where L_{ind} is the coefficient of self-inductance, a proportionality factor.

Self-inductance (L_{ind})

[electromagnetism, general] Proportionality that indicates the readiness of the MAGNETIC FLUX (Φ_m) to follow the change in current (I): $N_{\text{coil}}\Phi_m = L_{\text{ind}}I$, where N_{coil} represents the loops of the coil.

Semiconductors

[atomic, general, nuclear] Material made of ELEMENTS with specific ELECTRON configuration, for instance crystalline structures consisting of, but not limited to Galena, Silicon, Gallium or Germanium. An ATOM has the electrons arranged according to the BOHR ATOMIC MODEL with electrons in specific allowed ENERGY LEVELS or ORBIT SHELLS. In comparison with either INSULATOR or CONDUCTOR the electron configuration falls between these two. In an insulator the CONDUCTION BAND containing FREE ELECTRONS is unpopulated and separated by a forbidden gap from the VALENCE BAND, whereas in conductor configuration the valence band is overlapping the conduction band, hence populating the conduction mechanism of action with free electrons. In electron device fabrication the concept of DOPING refers to the introduction of foreign atoms into the LATTICE structure or random atomic structure of the semiconductor decreasing the gap between the conduction band and the valence band, hence lowering the ENERGY requirements to initiate conduction. Two kinds of doping can be used: *N-TYPE* referring to the introduction of an atom with an excess odd number of valence electrons (for instance, arsenic with five valence electrons) which can be transferred to the conduction band of the semiconductor atoms. The other doping is *P-TYPE*, referring to a deficiency in electrons (i.e., hole) in the valence band, such as three valence electrons in GALLIUM, which will retrieve loosely bound electrons for instance from the semiconductor Silicon. Both *n*-type and *p*-type doped semiconductors create an adjustable conductor, which can be turned into a conductor by an externally applied electric field. In electronic device design *p*-type and *n*-type materials are matched in various combinations: *pn*-JUNCTION, and sandwich structures: pnp, and npn and the like. In the energetic configuration the *p* and *n* structure are separated by a DEPLETION LAYER that forms a transition between the energy levels in the respective media. These combinations can create a DIODE or TRANSISTOR respectively and more complex INTEGRATED CIRCUITS.

Semipermeable membrane

[biomedical, chemical, thermodynamics] Membrane that will permit selective transportation of ions and molecules based on charge and size respectively or combined (see [Figure S.47](#)).

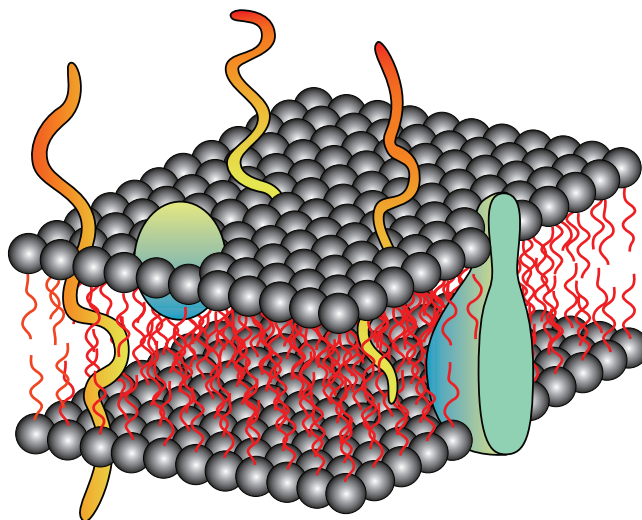


Figure S.47 Semipermeable membrane.

Separation boundary layer

[fluid dynamics] In fluid flow the LAMINAR FLOW may be disturbed by surface features with respect to the flow lumen that cause TURBULENCE that can be confined to a layer that is attached to the surface starting at the “point of separation” at the WALL. The flow outside the separation layer will maintain the original laminar profile and can be initiated at an abrupt change in radius or localized attachments, such as rust or plaque (biological vascular atherosclerosis).

Separation of variables

[computational, nuclear] Mathematical method for solving convoluted expressions, that use more than one dependent variable by separating the dependent variables out as independent variables. In spherical coordinates this yields: $\Psi(r, \theta, \phi) = R(r)\Theta(\theta)\Phi(\phi)$, giving three functions that can be solved independently, in this case with respect to radius (r), azimuth ANGLE (θ) and ZENITH ANGLE (ϕ).

Sextant

[computational, general, geophysics] Instrument used by sailors in the late seventeenth and most of the eighteenth century for navigation at sea. The sextant can determine the ANGLE between two points in a distant field, such as celestial objects and when the location of one of the objects is known as a function of time, the other object can provide the mechanism for determining the orientation as well as latitude and longitude of the location from which the MEASUREMENT is made. The device uses two mirrors that can be used to merge (superposition) the images of two objects by adjusting the angle of the second MIRROR, yielding the angle of the second object (e.g., the SUN) with respect to the first (i.e., the horizon).

The accuracy of the sextant is 10 s, where a degree is subdivided in 60 minutes and a minute in angle is subdivided in 60 s (see [Figure S.48](#)).



Figure S.48 Sextant.

Shadowgraph method

[acoustics, fluid dynamics, optics] Imaging method that uses the optical BIREFRINGENCE in a medium to indicate temporal and spatial gradients and discontinuities. The imaging mechanism relies primarily on transmission of LIGHT, and is used to highlight TURBULENCE and Mach-lines in fluid-flow with respect to steady-state or moving objects. Acoustic WAVE propagation can this way by illustrated due to the density gradient for the trough and crest regions (*also see* SCHLIEREN IMAGING) (see [Figure S.49](#)).

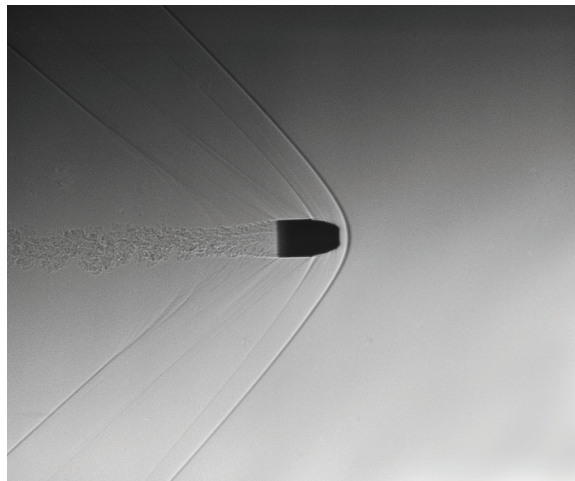


Figure S.49 Shadowgraph from a flying bullet, using the birefringence of the Mach-line edge of the wave-front.

Shaft horsepower

[fluid dynamics] The power produced by the shaft of a PUMP, or PROPELLER after the transferal by a gear system from the ENGINE classified by engine horsepower (the power output of the engine itself). Even though horsepower is not a standard unit it is still used in general descriptive specification, such as for a car, boat or compressor. The conversion from HORSEPOWER (*hp*) to the SI unit Watt is: $1 \text{ hp} = 0.745699872 \text{ kW}$. Also referenced as break-horsepower.

Shallow-water tides

[fluid dynamics] Tidal movement in shallow seas and estuaries. The movement of water in shallow seas is hardly affected by the gravitational influences from the SUN and MOON as in the deep water TIDAL MOTION described by PIERRE-SIMON DE LAPLACE (1749–1827) in 1775 when he developed the dynamic theory of tides, in follow-up on the work by DANIEL BERNOULLI (1700–1782) in 1740. In shallow seas and estuaries the tides are a fluid-dynamic response to the deep-water tides based on restrictive flow due to a gradient in water level at the inflow and outflow point(s) with respect to deep sea tidal motion. Tides are WAVE that conform to special formulations of the WAVE-EQUATION, where the solar influence is strictly periodic (semidiurnal; twice daily), however the Moon will provide a modulation effect. Water is considered shallow when the depth is less than one twenty-fifth of the perceived tidal wavelength. Normal SURFACE WAVES can be represented by a PARTICLE at the surface moving in a circular pattern, however for shallow alter this motion becomes elliptical (see [Figure S.50](#)).



Figure S.50 Shallow water tides in Cornwall England, Polperro harbour.

Shannon, Claude Elwood (1916–2001)

[computational, electronics, imaging, theoretical] Mathematician and electronic engineer from the United States. Claude Shannon is best known for his SAMPLING theorem, also known as the Shannon–Nyquist

theorem, or plain Nyquist theorem. Claude Shannon may be considered as one of the initial explorers into the concept of information theory. Shannon was also a cryptographer (*also see* **HARRY NYQUIST** [1889–1976]) (see [Figure S.51](#)).

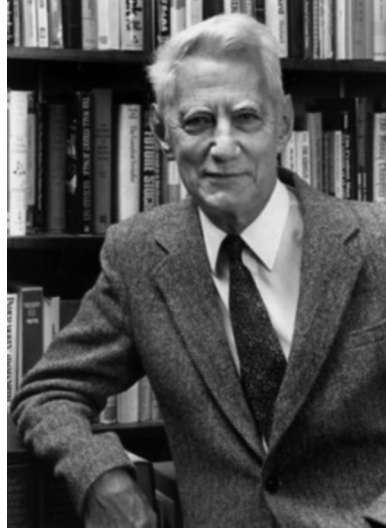


Figure S.51 Claude Elwood Shannon (1916–2001). (Courtesy of Bell Labs, Murray Hill, NJ, USA.)

Shannon entropy (H_S)

[imaging, theoretical] Measure of randomness and uncertainty in a parameter (χ) observed in a state-space coordinate system (Ω), expressed as $H_S(\chi) = -\int_{\Omega} p(\chi) \log p(\chi) d\chi$, where $p(\chi)$ defines the PROBABILITY density function of the variable χ . The Shannon entropy is used in IMAGE processing, specifically with respect to image registration. Also referred to as DIFFERENTIAL ENTROPY.

Shannon sampling law

[computational, thermodynamics] See **NYQUIST–SHANNON SAMPLING THEOREM**.

Shannon sampling theorem

[computational, thermodynamics] See **NYQUIST–SHANNON SAMPLING THEOREM**.

Shape factor

[atomic, imaging, nuclear] Descriptive form without specific defining magnitudes that relate to a specific functional purpose. Frequently represented by DIMENSIONLESS NUMBERS. In SIGNAL processing the shape-factor of a band-pass filter provides a spectral format, while in X-RAY crystallography the shape factor describes the correlation between the X-ray diffraction pattern and the crystallite structures; in fluid-dynamics this defines the BOUNDARY LAYER geography. In IMAGE analysis the shape factor determines the “compactness” of a shape. One example is the ratio of the area of a random shape to the comparative area of a circle which has the same perimeter, since the circle is the most compact shape, known as the isoperimetric quotient.

Shape memory alloys (SMAs)

[biomedical, mechanics] Memory material that will return to a preset shape (“memory”) when exposed to a predetermined temperature. The most used alloys is Nickel–titanium, known as NITINOL (known for the origin in 1961 Nickel Titanium Naval Ordnance Laboratory), additional alloys with shape retention are

copper–aluminum–nickel, copper–zinc–aluminum, and a variety of iron–manganese–silicon alloys. The memory effect can be explained by a crystal structure on an atomic level with an associated low equilibrium ENERGY which is accessed through a set of PHASE changes, known respectively as martensite and austenite, where the austenite phase is the “memory shape phase” of the configured alloy (see Figure S.52).

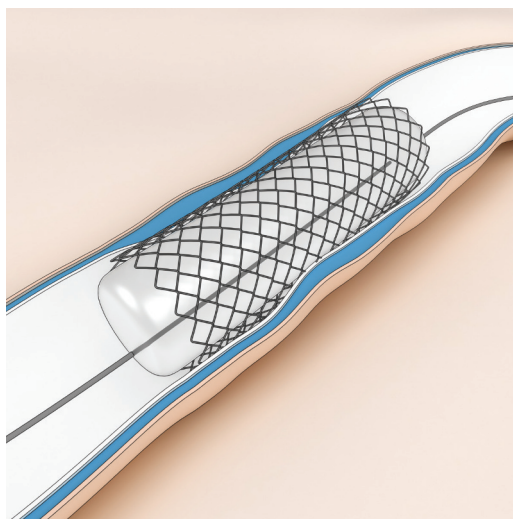


Figure S.52 Diagram of placement of Nitinol stent in blood-vessel.

Shark

[biomedical, general] Group of aquatic animals (i.e., fish) characterized by a cartilaginous skeleton, that in general has a highly evolved sensory system that relies on electrosense functionality; defined as electroreception, the ability to sense electric and MAGNETIC fields. Sharks also possess a pectoral fin that is not fused to the head, which increases its maneuverability. The electrosense is also found in birds to provide navigation. The shark uses the electrosense to detect prey based on cellular DEPOLARIZATION and muscular contraction. The sensing organ is modified epithelial tissue that forms specific sensory ELEMENTS call the Ampullae of Lorenzini. Certain well-known sharks are great white shark, tiger shark, mako shark, nurse shark, whale shark, and the hammerhead shark (see Figure S.53).

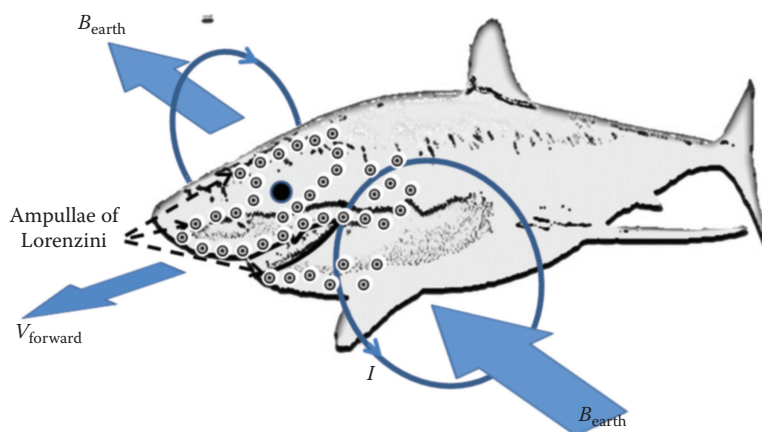


Figure S.53 Diagram of sensing organs of certain sharks used for detection of electromagnetic waves, both earth's magnetic field (static) and muscular contraction (dynamic; believed to reach up to 2 km distance in detection range).

Sharp series

[atomic, nuclear] Fine structure of spectral lines within the DOUBLET ATOMIC EMISSION lines of alkali metals representing transitions between the n^*s and the $2p$ electron configurations. This is placed in reference against the principal lines resulting from the n^*p to $2s$ electron configurations transitions, the diffuse lines of the transitions: $n^*d \rightarrow 2p$, and the fundamental lines of the $n^*f \rightarrow 3d$ transitions.

Shear flow

[fluid dynamics] For non-Newtonian liquids the stress appears as if it has a memory of prior conditions and the shear-stress is not a linear function of the flow gradient, however, depending on the LIQUID, become a function of the gradient as well as their derivatives; expressed in viscosity as $\eta(\dot{\mu}_s) = \eta(\dot{\mu})/\mu_s$, where $\mu_s = dx/dy$ is the shear strain and the rate of shear is $\dot{\mu}_s = [d(dx/dy)]/dt = D_{xy}$, also recognized as the velocity gradient.

Shear force

[biomedical, mechanics] Tangential component of a contact force, or the lateral force inside a deforming medium. Force that change the shape of an object without changing its volume. Shear stress is the ration of the shear force to the area involved, whereas shear strain is the ratio of deformation as the displacement of one level layer with respect to the DISTANCE to the fixed surface (see Figure S.54).

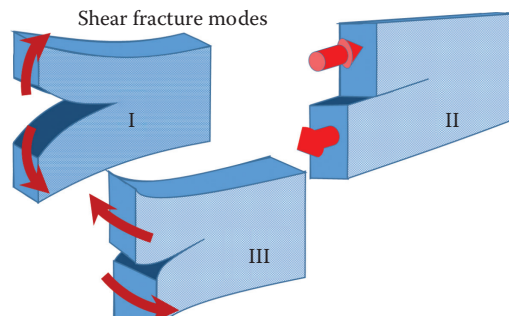


Figure S.54 Shear force: diagram of shear forces.

Shear Modulus (G_∞)

[acoustics, biomedical, computational, general, mechanics] Modulus of rigidity or stiffness. One of three parameters that are used to describe the stiffness and COMPLIANCE of a medium. The other two parameters are the YOUNG'S MODULUS and the BULK MODULUS. The shear modulus is defined as $G_\infty = \sigma_{xy}/\gamma_{xy} = (F/A)/(\Delta x/\ell)$, where $\sigma_{xy} = F/A$ is the shear stress, F the acting force parallel to the face of the object that is being deformed with surface area A , and the linear deformation of the position of the face with respect to the reference frame is Δx , which is applied over the height of the deformed object ℓ yields the shear strain: $\mu_{xy} = \Delta x/\ell = \tan \theta$, where θ represents the deformation ANGLE of the edge of the face plate with respect to the base (origin) of the object at rest. The Bulk modulus represents the response of a medium to an applied uniform pressure, whereas the Young's modulus defines the compliance in response to linear STRAIN (e.g., extension).

Shear Péclet number

[fluid dynamics, mechanics] See PÉCLET NUMBER, MASS TRANSFER.

Shear strain (μ_s)

[biomedical, fluid dynamics, general, mechanics] The ratio of lateral displacement (x) to the height with respect to the fixed surface (h): $\mu_s = x/h$ (see Figure S.55).

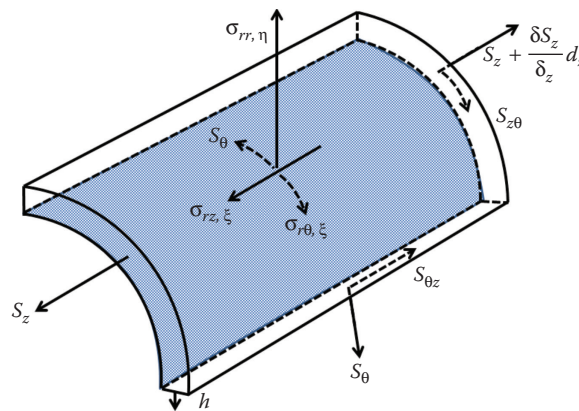


Figure S.55 Shear strain.

Shear stress (σ_s)

[acoustics, biomedical, fluid dynamics, general, mechanics] Ratio of SHEAR FORCE (F) to the surface area (A) that the force is applied to: $\sigma_s = F/A$. In ACOUSTICS the shear stress signifies the relative MAGNITUDE of the mean acoustic impedance across each respective layer or shear-surface (see Figure S.56).

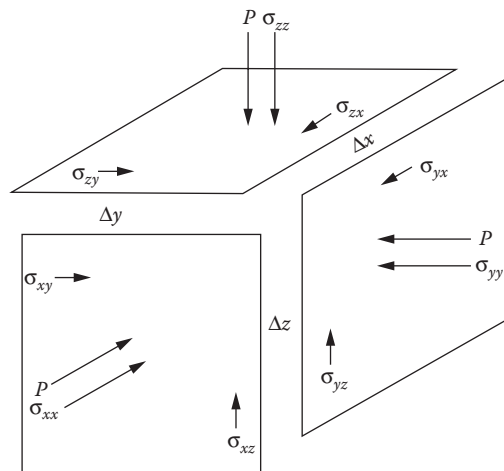


Figure S.56 Shear stress.

Shear-thickening fluid

[biomedical, fluid dynamics] Non-Newtonian fluid for which the VISCOSITY (η) increases with the flow velocity gradient $D = \dot{\gamma} = [d(dx/dy)]/dt \equiv (dv_x/dx) + (dv_y/dy)$, in turn the viscosity (η) is defined to behave according to: $\eta = K_{\text{mat}} \dot{\gamma}^{n-1}$, K_{mat} a material constant (see DILATANT FLUID and NON-NEWTONIAN FLUID) (see Figure S.57).



Figure S.57 Shear-thickening fluid. Silly-Putty® dripping through a hole in a Plexiglas® plate. Other applications are found in novel body-armor designs.

Shear-thinning fluid

[biomedical, fluid dynamics] Non-Newtonian fluid for which the VISCOSITY (η) decreases with the flow velocity gradient D (also see SHEAR-THICKENING FLUID; see PSEUDOPLASTIC FLUID and PSEUDOPLAST) (see Figure S.58).

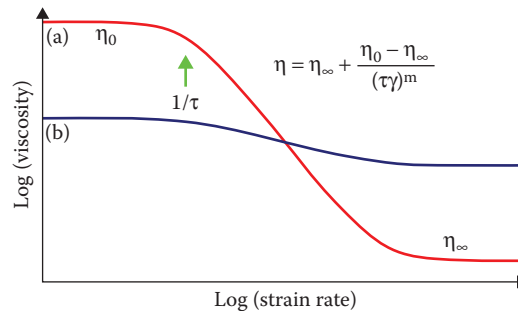


Figure S.58 Shear-thinning fluid.

Shedding frequency (ν_v)

[computational, fluid dynamics, mechanics, thermodynamics] Frequency of detachment of flow from a bluff or rounded surface such as under KÁRMÁN EDDY CURRENT VORTEX STREET development and maintenance. (see VORTEX SHEDDING FREQUENCY).

Shell model

[atomic, nuclear, solid-state, thermodynamics] The BOHR ATOMIC MODEL is constructed in shells, which are named in outgoing order as follows: K, L, M, N, O, P, and Q, corresponding with the PRINCIPAL QUANTUM NUMBER n , which is a positive integer and starts at $n = 1$ associated with the K-shell. The principal quantum number was the only QUANTUM NUMBER defined by NIELS HENRIK DAVID BOHR (1885–1962) in 1913 in his original atomic model. The electrons in the inner shell, the K-shell are tightly bound to the NUCLEUS and the most difficult to be excited, let alone extracted. The K-shell has only one SUBSHELL: 1s and can hold two electron only, with respective opposite SPIN. The orbital or azimuthal quantum number (second quantum number) of the K-shell is $\ell = 0$. The L shell consists of two subshells: 2s and 2p, providing for a total of two electrons in the 2s and six electrons in the 2p. The quantum number of the L-shell is $\ell = 1$. The M-shell has three subshells: 3s, 3p, and 3d, with the potential for harboring a total of 18 electrons (see BOHR ATOMIC MODEL) (see [Figure S.59](#)).

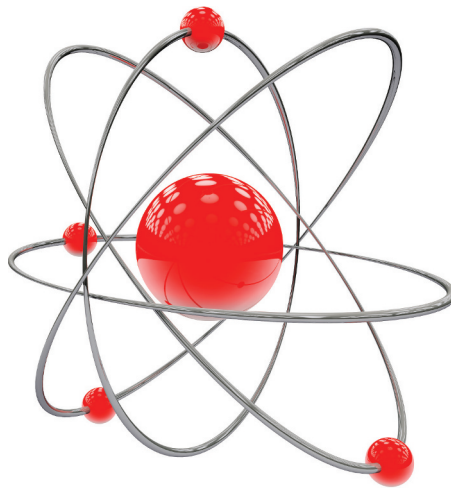


Figure S.59 Shell model.

Shepp-Logan phantom

[acoustics, biomedical, computational, general, imaging] Model of the human head introduced by Lawrence (Larry) Alan Shepp (1936–2013) and Benjamin Franklin Logan (1927–) in 1974 based on the geometric and Fourier decomposition of the general anatomical outline of the volumetric configuration of the generalized human head. The model has specific applications in validation of tomographic IMAGE reconstruction algorithms, specifically acting as attest-image for algorithm calibration in image

reconstruction with respect to TOMOGRAPHY (see POSITRON EMISSION TOMOGRAPHY [PET], COMPUTED TOMOGRAPHY [X-RAY CTR], and MAGNETIC RESONANCE IMAGING [MRI]) (see Figure S.60).



Figure S.60 Shepp-Logan phantom, three-dimensional rendering of the Shepp-Logan phantom used for image reconstruction algorithm testing shown in the image domain.

Sherwood number ($Sh = h_m L / D_{AB}$)

[biomedical, fluid dynamics] Dimensionless number identifying the concentration gradient at a surface, where h_m is the DIFFUSION rate, L the characteristic dimension, and D_{AB} the diffusion coefficient for the constituents A and B . The Sherwood number is the ratio of the mass DIFFUSIVITY with respect to the molecular diffusivity. In BLOOD flow the Sherwood number describes the PROBABILITY of SOLVENT desorption through the vascular WALL, where h_m now describes the wall permeability. The Sherwood number has various specialized definitions pertaining to specific geometries.

Shock absorber

[general, mechanics] Device that converts MECHANICAL ENERGY in other forms of energy, using fluid-flow or FRICTION mechanisms. The most well-known application of shock absorbers is on the axles of automobiles and motorcycles, compensating for unevenness in the road-surface and increasing the

traction stability by maintaining proper surface contact between the road surface and the tire surface (see Figure S.61).

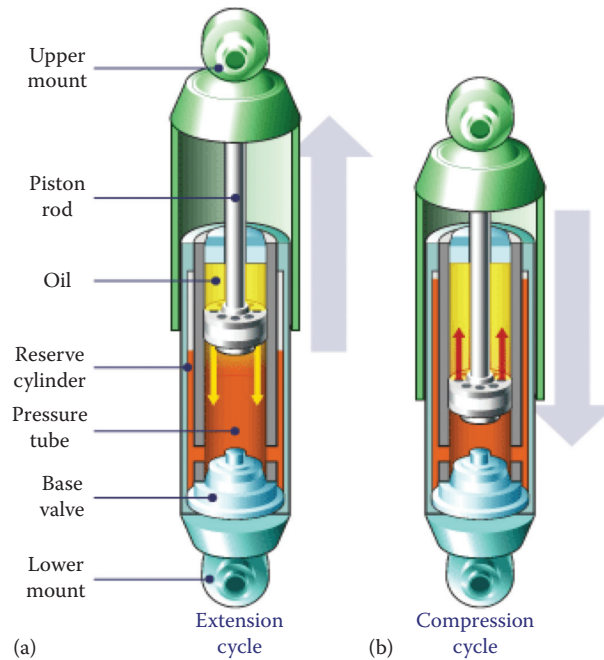


Figure S.61 Shock absorber: (a,b) diagram of operation and examples of use.

Shock wave

[fluid dynamics, general] Abrupt change in pressure, generating a pulse propagation through a FLUID or a solid medium. One specific example is in EARTHQUAKE shock propagation. Other examples include the breaking of the sound BARRIER when flying and exceeding the Mach velocity, or bursting of a balloon. The shock-wave has an impulse due to the incremental change (see Figure S.62).

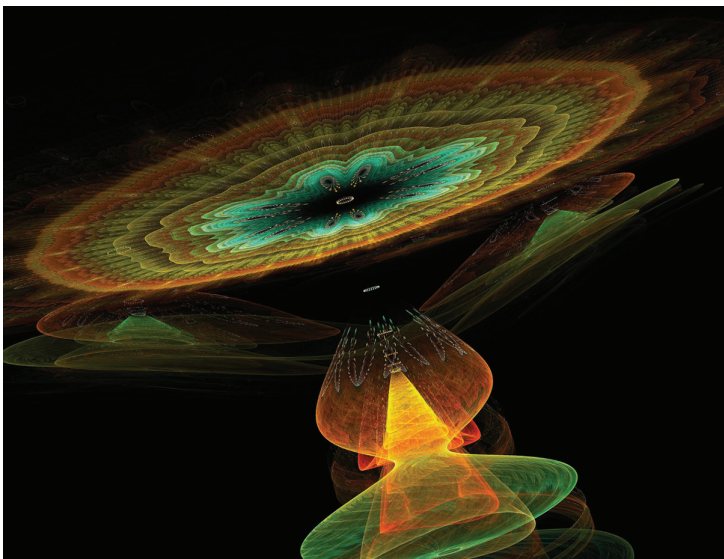


Figure S.62 Shock-wave.

Shunt

[biomedical, electromagnetism, fluid dynamics, general] By-pass mechanism that has the ability to mitigate risks and constraints that are present in the main line of a flow pattern. The flow can consist of fluids, charges, magma or gasses. On specific example of a biomedical fluid-dynamic shut is the bridging between a VEIN and an artery in the arm of a person with kidney problems to accommodate the high flow requirements for the KIDNEY dialysis equipment that is connected externally to the body (see [Figure S.63](#)).

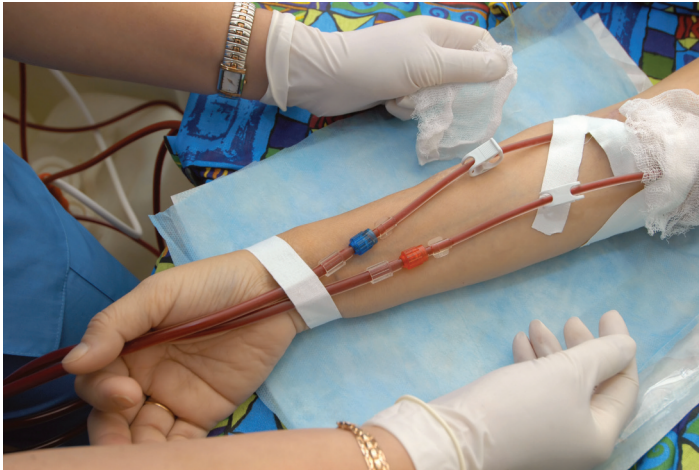


Figure S.63 Kidney dialysis shunt in arm of patient.

SI units

[general] See SYSTÈME INTERNATIONAL (D'UNITÉS).

Sievert (Sv)

[biomedical, electronics, nuclear] Unit used in RADIATION exposure to indicate the biological effect, not specifically the MAGNITUDE of radiation. The SI unit for the combined quantity and mechanism of delivery (alpha, beta or gamma rays) of ionizing radiation that will produce the same biological effect in comparison to one rad of X-RAY radiation exposure. The scale compares to the unit gray used in X-ray exposure.

Sievert, Rolf Maximilian (1896–1966)

[biomedical, electronics, nuclear] Radiologist from Sweden. Sievert's work focused on the biological effects of RADIATION, introducing the biological equivalence, later assigned the unit Sievert. Sievert also introduced a standard for measuring ABSORBED DOSE of radiation, described by the "Kerma rate"; the kinetic ENERGY absorbed per unit mass. The AIR Kerma rate ($\dot{K}_{\text{air},P}$) is associated with nonionizing radiation (IONIZATION is secondary effect) in air, associated with photons, neutrons, and fast neutrons, expressed as $\dot{K}_{\text{air},P} = A_{\text{cc}} \Gamma_{\text{AKR}} \int_{\theta_1}^{\theta_2} (e^{-\mu_{\text{en}} d / \cos \theta} / P^*) d\theta$, where A_{cc} the "activity" of the source (rate of emission), Γ_{AKR} the Air-Kerma rate constant (this is linked to the exposure rate constant of the radiation), μ_{en} is the radiation attenuation coefficient, d is the source material thickness, $P^* = Lb'$, with L the length of the source, b' the DISTANCE from source to target, θ the angular field-of-view. A similar approach applies for water. This is important in brachytherapy, a form of RADIATION THERAPY where the radiation source is implanted in close

proximity to the volume that requires treatment; radiation seed implants as used for instance in prostate therapy (see [Figure S.64](#)).

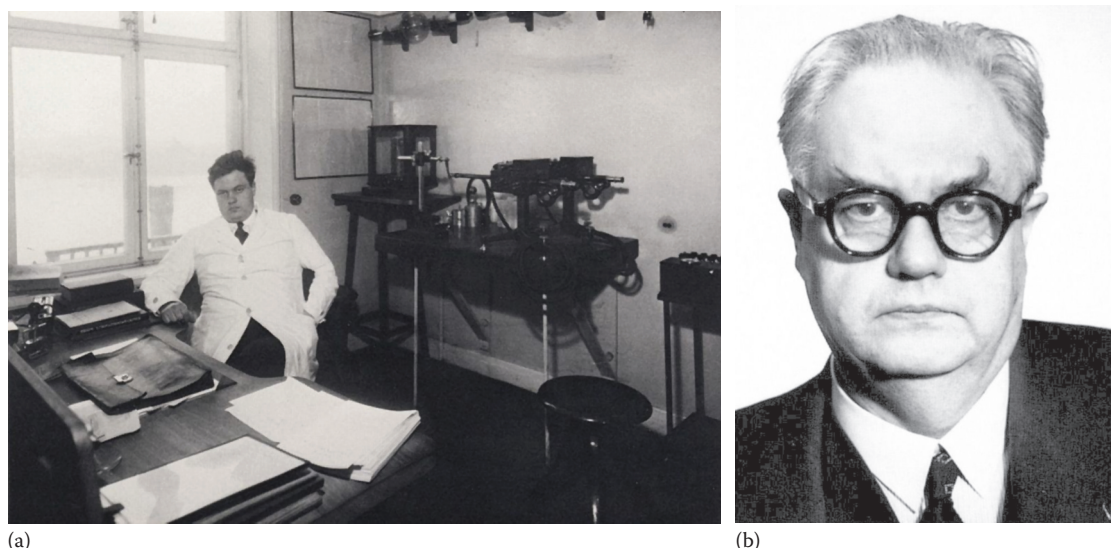


Figure S.64 Rolf Maximilian Sievert (1896–1966), (a) in 1958. (Courtesy of Kungl. biblioteket, National Library of Sweden, Picture collection, KoB, Fc) and (b) photograph by Hans Weinberger.

Sigma particle

[atomic, nuclear] BARYON particle. Particle in the family of HADRON subatomic elementary constituents. Unstable hyperon with ELECTRIC CHARGE +2, +1, −1, or zero and strangeness −1.

Signal

[acoustics, biomedical, electronics, general, mechanics, optics, quantum] Stream (temporal) or distribution (spatial) of data. Signals can be described in one or more dimensions. A one-dimensional SIGNAL is an orderly sequence of numbers that describes the modulations and trends of a parameter. The successive acquisition of a physical quantity over time is the typical signal found in science and ENGINEERING. The temporal order of the numbers in a signal is a direct function of the order of events (i.e., measurements) in “time.” The characterization of a signal is defined by the order in which the data points are collected as well as the MAGNITUDE (amplitude) of the recorded numbers. Signal processing provides the tools to analyze the signal in order to extract important knowledge that may not be directly visible to the HUMAN EYE. One-dimensional signals are not necessarily ordered in time alone, the data-points may be location specific derived from a sensor array. The aspect of “time” forms the primary basis to describe the axis that identifies order. The temperature of a METAL rod as a function of location along the length is not directly a function of time, however the location-specific temperature may still be time dependent. In biomedical data acquisition the recording of the electrical activities of the DEPOLARIZATION of the HEART muscle is referred to as the ELECTROCARDIOGRAM (ECG), which is the main diagnostic signal in assessment of the cardiovascular system and general health, hence it is part of the “vital signs.” Multidimensional signals are the extensions or convolution of the one-dimensional signals. An IMAGE is a two-dimensional array of data. In a grey-scale image, the signal magnitude for a specified set of coordinates (x, y) identifies the level of brightness of the image at those coordinates, expressed by the response function $g(x, y)$. Signals identify the mechanism to obtain critical information about the origins of a phenomenon, based on the method of acquisition and the applied computational processing algorithm(s). Three types of signal can be recognized: analog, discrete, and digital. Analog signals are continuous both in time and amplitude, discrete signals are intermittent burst of continuous amplitude, the digital signal relies on encoding for the information, and both time

and amplitude are discrete. Neural impulses are a specific example of digital signals, whereas in most other scientific applications an analog-to-digital (AD) conversion is required (see Figure S.65).

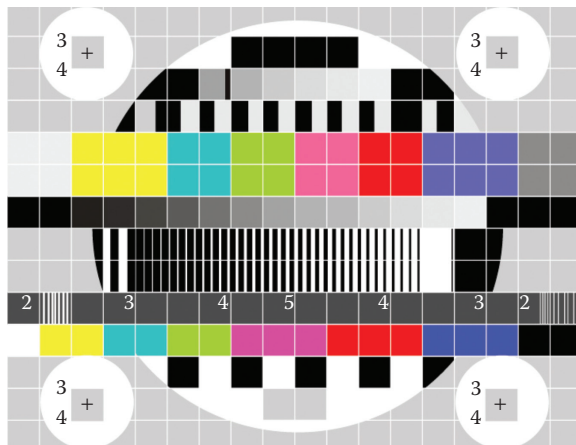


Figure S.65 Signal.

Signal-to-noise ratio (S/N or SNR)

[acoustics, biomedical, electronics, general, mechanics, optics, quantum] Quality measure for the reliability and accuracy of a SIGNAL with respect to other measured data-points that are not directly related to the MAGNITUDE of a phenomenon (i.e., NOISE; also referred to as background, or background-noise). The signal-to-noise ratio is generally defined as the power (generally defined proportional to the AMPLITUDE squared) of the signal (P_{signal}) divided by the power of the noise (P_{noise}): $\text{SNR} = P_{\text{signal}}/P_{\text{noise}}$, for an alternating signal with mean amplitude zero the signal-to-noise ratio can be expressed as a function of the variance for the respective “signals”: $\text{SNR} = \sigma_{\text{signal}}^2/\sigma_{\text{noise}}^2$. In IMAGE processing a threshold for accuracy based on signal-to-noise is defined by the Rose criterion, stating $\text{SNR} \geq 5$ for well-defined feature analysis at 50% or better to distinguish the object from “background,” introduced in 1973 by the American physicist Albert Rose (1910–1990). The ratio is usually expressed in DECIBEL (dB): $\text{SNR}_{\text{dB}} = 10 \log_{10}(P_{\text{signal}}/P_{\text{noise}})$. Noise can be thermal (e.g., electronic influence produced by charge agitation) or result from the ambient conditions, such as equipment switching or in ACOUSTICS the voices of bystanders. Noise is a random feature that can provide a large magnitude data point produced by the equipment used to collect the features representing specific physical consequences (see Figure S.66).



Figure S.66 Signal-to-noise ratio: example of sinusoidal signal with imbedded noise, and noise alone.

Silastic™

[biomedical, chemical, mechanics] Highly configurable, inert silicone rubber, specifically used in prosthetic devices. Introduced by Dow Corning®.

Silicon (Si)

[chemical, solid-state] ELEMENT $^{28}_{14}\text{Si}$, metalloid, discovered in 1823. Electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^2$; with electrons in the consecutive shells: 2, 8, 4. Silicon is the world's second most prevalent element, by mass (after oxygen), however virtually never found in pure form. The most common form is in silicate minerals, some forming the basis for what is known as sand. Silicon forms a major constituent in the popular chemical composite Silicone, as well its wide use in semiconductor design (see SILICONE RUBBER, SEMICONDUCTOR, and *pn*-JUNCTION) (see Figure S.67).

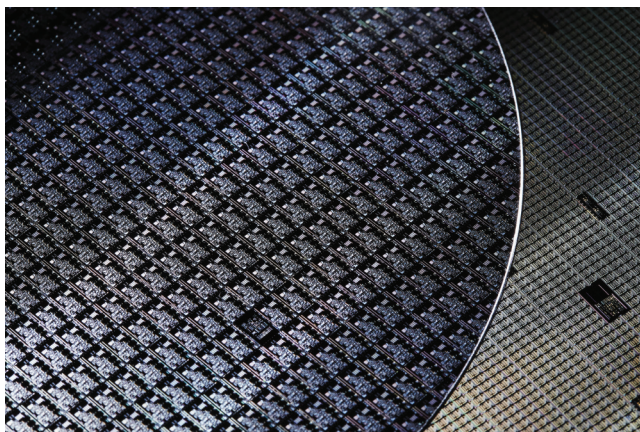


Figure S.67 Silicon wafer of semiconductor fabrication.

Silicon nitride

[biomedical, chemical] White chemically inert compound consisting of the ELEMENTS silicon and nitrogen (Si_3N_4), and may be classified as a ceramic. Silicon-nitride is a solid with a high-melting-point of $\sim 1900^\circ\text{C}$. Silicon-nitride has excellent shock RESISTANCE and high durability and is used in many applications that have impact or VIBRATION risks, such as the automotive industry (e.g., cylinder lining, bearings) and medical devices as an alternative to TITANIUM and PEEK (polyether ether ketone), and is used for instance in orthopedic applications such as spinal FUSION devices.

Silicone rubber

[biomedical, chemical, mechanics] Mixed inorganic–organic ELASTOMER composed of a silicon-POLYMER, consisting of the ELEMENTS silicon (Si), CARBON (C), hydrogen (H), and oxygen (O), based on a silicon-oxygen backbone. Silicone has the following generic chemical formula $[\text{R}_2\text{SiO}]_n$, where R represents an organic group, for instance: ethyl, methyl, or phenyl. Silicone has found many applications, ranging from house-hold sealers to medical applications, specifically breast augmentation inserts. The high temperature range makes the material very attractive, operational from -100°C to $+300^\circ\text{C}$. Silicone has very durable properties, including resilient chemical, mechanical and THERMODYNAMICS properties under a wide range of conditions and exposure to external influences. Silicone was first produced by Dow Corning® in 1943, and was invented around the turn of the century, beginning of the twentieth century by the British chemist Frederick Kipping (1863–1949) who also coined the term silicone. The concept was rapidly picked up by General Electric (GE), now under the company name “Momentive Performance Materials,” as well as “Wacker Chemie” and “Shin-Etsu Chemical” in the late 1940s and early 1950s. Only a select group of manufacturers produces Silicone. As a lubricant the most well-known form is polydimethylsiloxane

(PDMS), in OIL consistency. Recent advance introduced silicon in a self-healing elastomer format (see Figure S.68).



Figure S.68 Silicone rubber and example of use: gel.

Simple harmonic motion

[general] A MOTION is harmonic when the FORCE (F) on the object in motion is directly negatively proportional to the body's displacement (s), for instance under the influence of a spring-force or under GRAVITATION force (i.e., simple PENDULUM). The SPRING FORCE for a MASS-SPRING SYSTEM is defined by $F = -ks = ma$, where k is the spring constant and a the acceleration of the mass m . The displacement of the object around the point of equilibrium ($s = 0$) needs to be small enough to satisfy $F(s) = \left[\frac{dF(s)}{ds} \right]_{s=0} s$. The motion needs to satisfy the following equation: $(d^2s/dt^2) + (k/m)s = 0$. The motion by the body varies sinusoidally with time and can generally be described by sine and cosine functions or in complex notation including the range of motion called AMPLITUDE (A), the FREQUENCY ($\nu = \omega/2\pi$) (or angular frequency: $\omega_0 = \sqrt{k/m}$, also called the NATURAL ANGULAR FREQUENCY), period ($T = 2\pi/\omega$) and PHASE ($\omega t + \phi$; with phase constant: $\phi = \tan^{-1}(\omega s(t)/v(t))$, with) of the location, all as a function of time; that is, $s(t) = A \sin(\omega t + \phi)$. For the simple pendulum with length: ℓ , the harmonic deviation is in the ANGLE: θ the harmonic oscillation satisfies: $(d^2\theta/dt^2) + (g/\ell)\sin\theta = 0$, which for small deviations reduces to: $(d^2\theta/dt^2) + (g/\ell)\theta = 0$. Harmonic oscillators appear in many locations, on an atomic level it accounts for the temperature effects, while RESONANCE plays a major role in musical instruments, whereas most phenomena are damped oscillations. An OSCILLATION under constant reinforcement (i.e., applied mechanism of force) will result in resonance (*also see* MASS-SPRING SYSTEM) (see Figure S.69).



Figure S.69 Illustrations of simple harmonic motion with wave pattern.

Simpson's rule

[computational] Method used in NUMERICAL integration, providing exact solutions up to polynomials of the third power. Simpson's rule is most elegantly implemented by integration of a third-order Lagrange interpolating polynomial fit ($f(x)$) to the base function of the integral, taken at three points, performing the equivalent linear interpolation at three equally spaced points, separated by a DISTANCE ℓ :

$$\int_{x_0}^{x_1} f(x) dx = \int_{x_0}^{x_0+2\ell} f(x) dx = \frac{1}{3} \ell (f_0 + 4f_1 + f_2) + \frac{1}{6} \int_{x_0}^{x_1} (x_0 - x')^2 (x_1 - x') f^{(3)}(x') dx' \\ + \frac{1}{6} \int_{x_0}^{x_1} (x_2 - x')^2 (x_1 - x') f^{(3)}(x') dx' = \frac{1}{3} \ell (f_0 + 4f_1 + f_2) - R_{\text{rest}}$$

where f_n represents the function at the respective interpolation points: $f_n = f(x_n)$, and $R_{\text{rest}} = (n\ell^5/90)f^{(4)}(x^*)$ the error term using the fourth order derivative.

Simulated annealing

[computational] Mathematical approach in PROBABILITY used for solving problematic SOLUTION techniques involving combinatory methods. It may be improbable to find an optimal solution, however a reasonably good solution may be derived under simulated annealing probability optimization. One particular example is the process of mimicking misplaced atoms in a METAL undergoing heating followed by a slow cooling process, often termed the "traveling salesman" problem. The salesman must optimize (minimize) the mileage traveled for work based on the itinerary spread over randomly located locations in multiple cities, this is done by pairwise trading the order of visits, finding a local minimum, without ever reaching a global minimum. Certain trades in the order in which places are "visited" may have no impact on the direct outcome, but may lead to reductions further down the path.

Simultaneity

[nuclear, relativistic] Under relativistic concepts two events that happen at the same time (e.g., two simultaneous observations) may not be perceived as simultaneous for two different observers due to two different concepts of time for the respective observers.

Single photon emission computed tomography (SPECT)

[biomedical, imaging] Imaging modality that acquires information with respect to the concentration of radio-nuclides that have been previously introduced into the patient's body. SPECT has its origin in the early 1960s, when the idea of emission traverse section TOMOGRAPHY was introduced by the physician DAVID EDMUND KUHLE (1929–) and the engineer ROY Q. EDWARDS (mid twentieth century–) prior to the introduction of the imaging mechanisms of positron emission tomography (PET), X-RAY computed tomography, or magnetic resonance imaging (MRI). SPECT imaging is inferior to PET because of attainable RESOLUTION and sensitivity. Different radionuclides are used for SPECT imaging that emit a single PHOTON (usually with ENERGY of about 140 keV), rather than positron emission (resulting in two high energy 511 keV photons) as in PET. Because only a single photon is emitted from the radionuclides used for SPECT, a special LENS known as a collimator is used to acquire the IMAGE data from multiple views around the body. The use of a collimator results in a tremendous decrease in detection efficiency as compared to PET. For positron emission tomography, location and collimation is inherently achieved by the fact that the pair of detected photons (gamma rays) can be traced back to their origin since they travel along the same line, in opposite direction, after being produced. In PET, in excess of 500 detectors are used to detect a PET ISOTOPE at any one time whereas in SPECT, there the imaging relies on only one or three collimators. Although the SPECT imaging resolution is not nearly as high as that of PET, the availability of specific SPECT radiopharmaceuticals, and the economic aspects of SPECT as well as the practical implications of the instrumentation make this mode of emission tomography particularly attractive for clinical studies of the brain. The cost of SPECT imaging is about one third that of PET.

Single photon photoelectric effect

[general] The photoelectric effect is the result of photons liberating electrons from the VALENCE BAND of a METAL. The MINIMUM ENERGY requirement for the generation of a PHOTOELECTRON is called the work-function and is a function of the material: $E_{\text{work}} = h\nu_0 = \phi_w$, where $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is PLANCK'S CONSTANT, ν_0 the threshold frequency of electromagnetic RADIATION. A single photon can generally liberate only one electron (conversion into kinetic energy), where sometime multiple photons of low energy can combined release an electron. Since the photoeffect can be considered to be a single photon effect the total number of photons is generally immaterial to the energy of the ejected electron.

Single-slit diffraction

[general, optics] Experimental design first executed by JOSEPH VON FRAUNHOFER (1787–1826) around 1814. The far-field INTERFERENCE pattern resulting at a distant screen can be interpreted as having an infinite number of individual sources spread out over the width of the opening of the slit, creating individual Huygens wavelets (see HUYGENS PRINCIPLE). The locations of the minima (dark space) resulting from cancellation interference are spaced from the central maximum directly under the center of the slit described as $b \sin \theta = m\lambda$, where b is the width of the slit, θ the ANGLE with the central axis, m an integer, and λ the respective wavelength within the source LIGHT. The intensity measured electronically is defined as $I = I_0 (\sin \beta_{\text{Fr}} / \beta_{\text{Fr}})^2$, where $\beta_{\text{Fr}} = \pi b \sin \theta / \lambda$; note that the intensity of electromagnetic RADIATION does not exist, since there are two components to the WAVE; the MAGNITUDE of EM radiation is provided as radiance or fluence, depending on the geometry of impact. Compare to FRESNEL DIFFRACTION in the near-field (see Figure S.70).

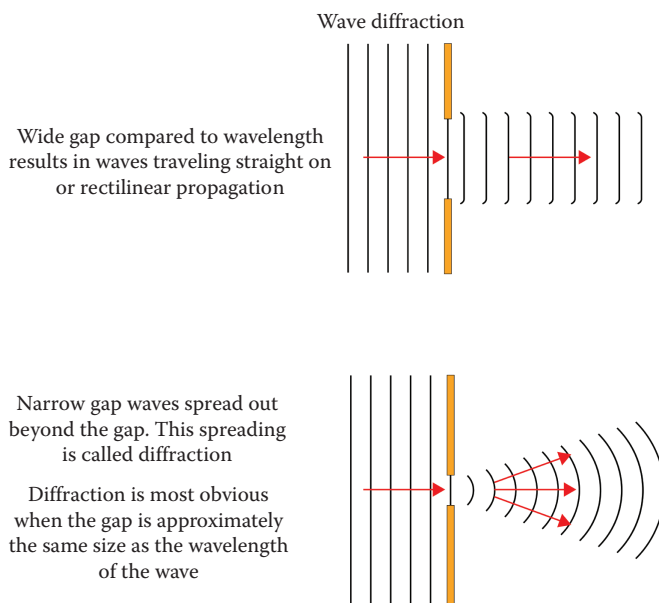


Figure S.70 Graphical representation of the formation of the Single-slit diffraction pattern.

Singlet scattering length

[nuclear] During the RADIATIVE CAPTURE of an incident NEUTRON by a PROTON a characteristic length can be identified as the s-wave elastic triplet scattering probability (singlet): $a_{f(s)} = -f_{t(s)}(0)$, where $f_{t(s)}$ is the singlet scattering AMPLITUDE; $\hat{f}(k) = f_t(k)\hat{Q}_t + f_s(k)\hat{Q}_s$, with $\hat{Q}_t = (3\hat{I} + \hat{\sigma}^{(n)}\hat{\sigma}^{(p)})/4$, $\hat{Q}_s = (3\hat{I} - \hat{\sigma}^{(n)}\hat{\sigma}^{(p)})/4$, $\hat{\sigma}^{(n)}$, and $\hat{\sigma}^{(p)}$ the Pauli SPIN operators for the neutron and proton respectively, $\hat{I}$ the fourth row unit matrix; and k the wavenumber with $p = \hbar k$ the neutron momentum defined in the center-of-mass for the neutron-proton system, $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is PLANCK'S CONSTANT.

Singlet state

[atomic, nuclear] Any pair of particles with spin-1/2 can form total spin 1 in three different states, which is called a triplet, alternatively they combine to form a state of spin 0, the singlet state. The singlet state represents a TOTAL ANGULAR MOMENTUM of zero for a group of particles or represents a vanishing PARTICLE. The component can switch between triplet and singlet state multiple times during an extensive period and may prefer the singlet state. Oxygen however is preferably in TRIPLET STATE, however a singlet state can be configured, which is poisonous to many biological systems, specifically used in cancer therapy. Singlets occur both in atomic and nuclear configurations. In hydrogen two electrons are antiparallel in the ground-state forming a singlet, however the protons are in triplet state, creating an ENERGY configuration that is degenerate (see Figure S.71).

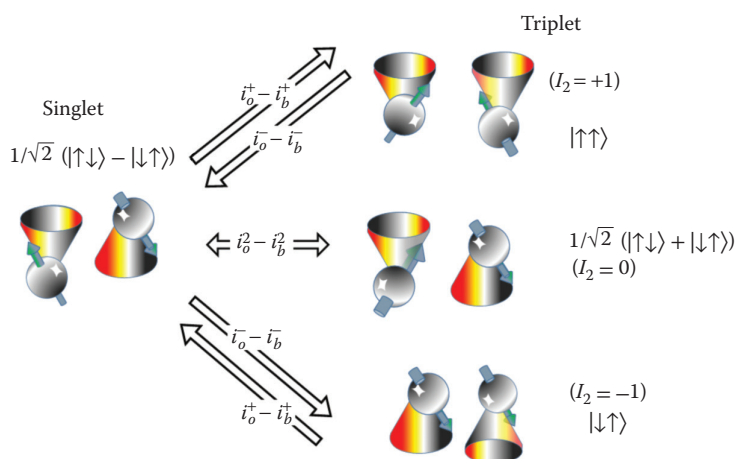


Figure S.71 Diagram of singlet atomic state of excitation and energy transfer states. The singlet state is highly reactive and in photodynamic therapy, singlet oxygen is the reactive oxygen that initiates the break-down of the cellular nucleus by oxidation and decay, resulting in cell-death.

Singularity

[computational] Location in space where a mathematical function (and hence the described phenomenon) cannot exist. In calculations these points will need to be avoided. For instance the expression $1/r$ will let the function go to infinity at the origin (see Figure S.72).

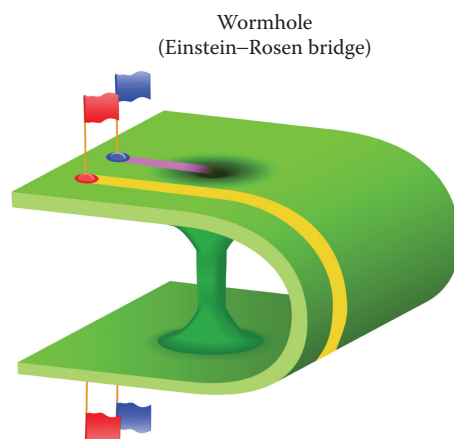


Figure S.72 Example of singularity: worm-hole diagram, galactic space discontinuity.

Sink and source

[fluid dynamics] Modeling concept in fluid-dynamics describing the flow pattern definition with respect to a theoretical source. In case the source is negative this becomes a sink. The velocity profile expressed in spherical coordinates is $v_r = \Lambda/2\pi r$ and $v_\theta = 0$, where r is the radius to the center of the phenomenon, and Λ the source strength, specifies the rate of volume flow going outward with respect to the source; when negative the flow is inward. The corresponding flow potential is $\phi(r, \theta, \phi) = (\Lambda/2\pi) \ln r$, and the **STREAM FUNCTION** is defined as $\psi(r, \theta, \phi) = (\Lambda/2\pi)\theta = (\Lambda/2\pi) \arctan(y/x)$.

Skeggs, Leonard T. Jr. (1918–)

[biomedical, chemical] Chemist from the United States. Skeggs received recognition for his discovery of two angiotensin peptides in relation to hypertension (high blood-pressure, predominantly with respect to a **SYSTOLIC PRESSURE** over 140 mm Hg, but a **DIASTOLIC PRESSURE** exceeding 90 is gaining more importance) through the angiotensin converting enzyme. Additional work of Skeggs resulted in significant improvements in **KIDNEY** dialysis procedures (see [Figure S.73](#)).



Figure S.73 Leonard T. Skeggs, Jr. (1918–).

Skeletal muscle

[biomedical, mechanics] In tissues there are three prominent types of muscles, skeletal muscle, cardiac muscle and smooth muscle. Skeletal muscle is attached to the bone structure of vertebrate animals and provides a mechanism to apply force and torque and yield movement and displacement (see **MUSCLE**).

Skin

[biomedical, chemical, general] Part of **ANATOMY**, organ for many classes of animals, primarily applies to vertebrates. Most known for the human skin. The skin is a multilayered structure with several attributes, such as imbedded sensors for touch, temperature, pressure as well as vascular integration to provide nourishment to sustain the biological functions. Parts of skin are semipermeable membranes that allow sweat

to pass through but also provide a mechanism for chemical interaction (e.g., allergens) and specifically drug delivery. Skin can have a specific COLOR resulting from dye MOLECULE concentrations called carotene and melanin, in collaboration with hormonal influences, such as androgens. For humans the skin is the second largest organ next to the lung in surface area. Skin has three layers: the outermost layer epidermis; directly beneath the epidermis is the dermis, containing connective tissue, hair follicles, and sweat glands; the deeper hypodermis primarily consists of fat and connective tissue. The epidermis forms a waterproof BARRIER and form the skin-tone. The skin has certain electrical, physiological, and chemical properties that are used for diagnostic interventions as well as derived applications. Some of the nonspecific applications are in the lie-detector test, and more recently in bioelectric power supply for in situ monitoring devices (see Figure S.74).

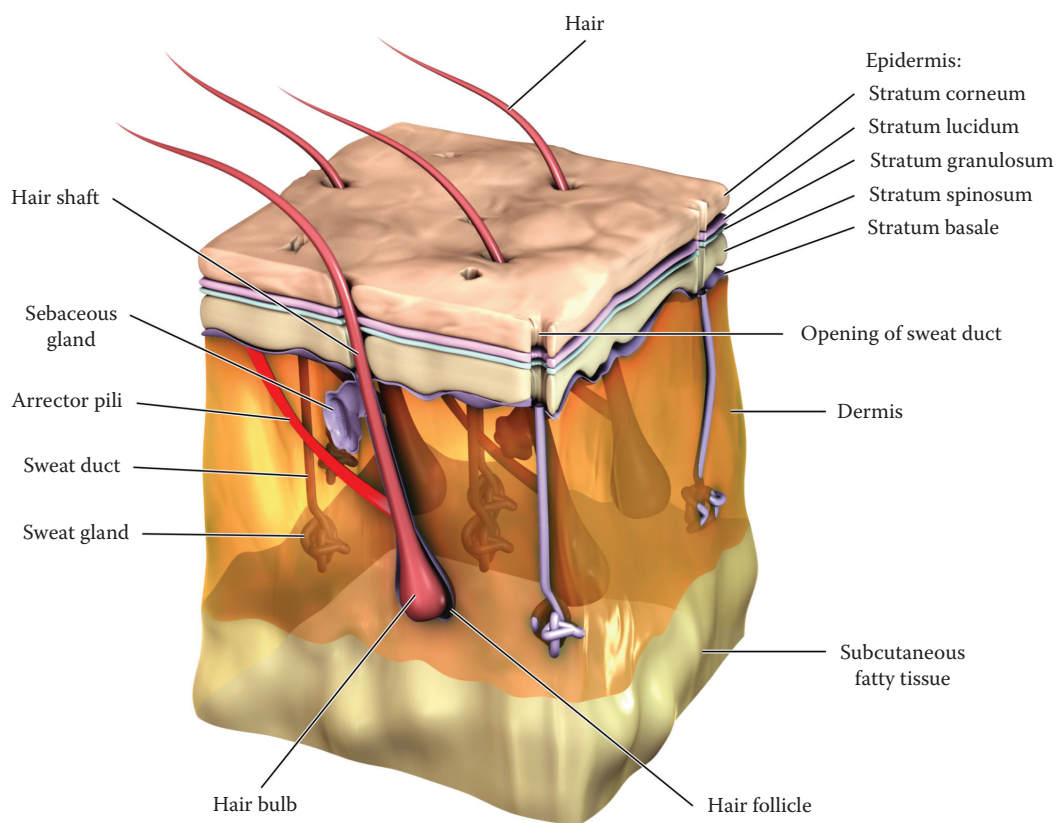


Figure S.74 Skin, human skin diagram of anatomical structure.

Slater determinant

[atomic, chemical, mechanics] An expression that describes the wavefunction (as SOLUTION to Schrödinger's equation) of an anti-symmetric system consisting of *more than two* fermionic configurations (e.g., electrons) that consequently satisfies the PAULI EXCLUSION PRINCIPLE. The anti-symmetry and Pauli exclusion are rolled together in the fact that the system changing sign when exchange of fermions takes place. The principle was introduced by John C. Slater (1900–1975) in the 1930s. The principle relies on approximation of the WAVE function for a many-particle system by SEPARATION OF VARIABLES, implementing the product of orthogonal wave functions of the individual particles that may be chosen appropriately based on the local conditions.

Specific applications are in atomic orbits and molecular electron orbits. The radial function is as follows: $R(r) = Nr^{n-1}e^{-\chi r}$, where n has the function of PRINCIPAL QUANTUM NUMBER, N a NORMALIZATION factor, r the radius, and χ provides the charge compensation for the NUCLEUS. The angular aspect of the Slater determinant is expressed in POLAR COORDINATES by the spherical harmonics: $Y_l^m(\vec{r})$. Also known as Slater orbital.

Slice

[imaging] Segment of computed TOMOGRAPHY data acquisition array that has one narrow dimension that is part of a stacked organization to form a three-dimensional reconstruction (see, for instance, PET, MRI, and X-RAY COMPUTED TOMOGRAPHY) (see Figure S.75).

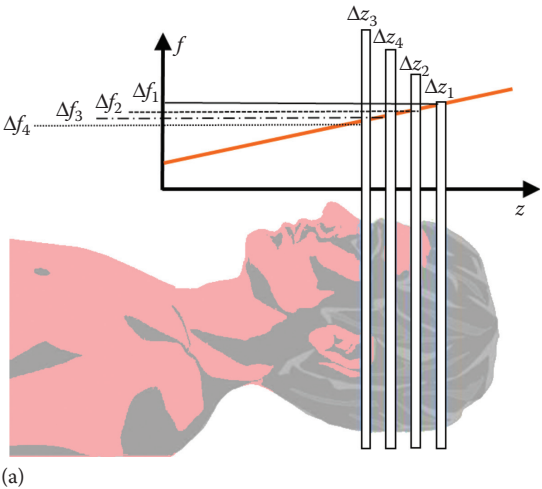
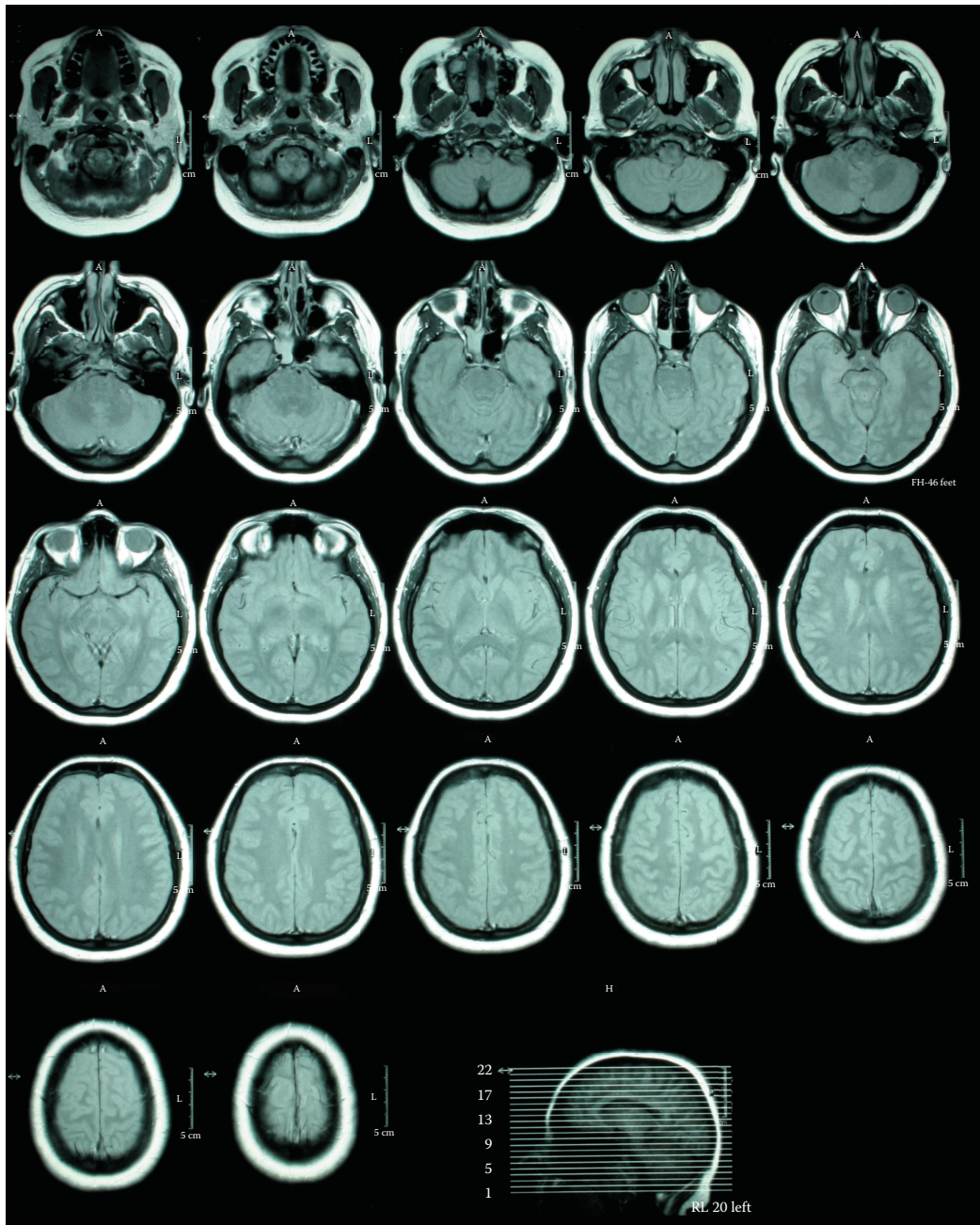


Figure S.75 (a) Representation of the “slice theorem” concept in imaging, where the object is sliced as if it were a piece of fruit. (Continued)



(b)

Figure 5.75 (Continued) (b) The slice thickness (Δz) will determine the lateral resolution as exemplified for the magnetic resonance imaging diagram as a function of frequency modulation (Δf). Generally the slices are presented next to each other for evaluation.

Smoke method

[fluid dynamics] Visualization method for illustrating TURBULENCE effects. In gaseous FLUID flow the use of a smoke wire placed in the lumen of the flow can highlight the flow patterns. A specific example is the

formation of a torus of smoke indicating fluid rolling around a circular axis; or less prominent, spinning around an imaginary axis line that forms a closed loop (see [Figure S.76](#)).



Figure S.76 Example of the Smoke method.

Smyth report

[atomic, nuclear] Report on the MANHATTAN PROJECT by the American physicist Henry DeWolf Smyth (1898–1986), focusing on the Allied Forces effort in World War II to develop the ATOMIC BOMB (see MANHATTAN PROJECT).

Snel ("Snell"), Willebrord Snel van Royen (Snellius) (1591–1626)

[optics] Scientist and mathematician from the Netherlands. Snell described the path of LIGHT at the interface of two media with a discontinuity in index of refraction in 1621. Willebrord Snell changed his name to the Latin equivalent: Snellius in celebration of his scientific achievement. The work of PTOLEMY (90–168) and IBN SAHL (940–1000) may be considered to predate that of Snell but these scientists lacked the proper instrumentation at the time to define the exact geometric relationship mathematically. Additionally, RENÉ DESCARTES (1596–1650) described similar concepts in 1637 (see [Figure S.77](#)).



Figure S.77 Willebrord Snel van Royen (1591–1626).

Snel's Law

[acoustics, general, optics] See **SNELL'S LAW**.

Snell's law

[acoustics, general, optics] **LAW OF REFRACTION** discovered by **WILLEBRORD SNEL (SNELLIUS) VAN ROYEN** (1591–1626) described as $\sin \theta_i / \sin \theta_r = n_2 / n_1$, where θ_i is the **ANGLE** of incidence with respect to the normal to the surface at the interface between two media, incidence media with index-of refraction n_1 and continuing medium with index-of refraction n_2 , and θ_r is the angle of refraction into the second medium. The index of refraction will depend on the material properties of the medium as well as the **WAVE** phenomenon itself (e.g., mechanical, electromagnetic) (see [Figure S.78](#)).

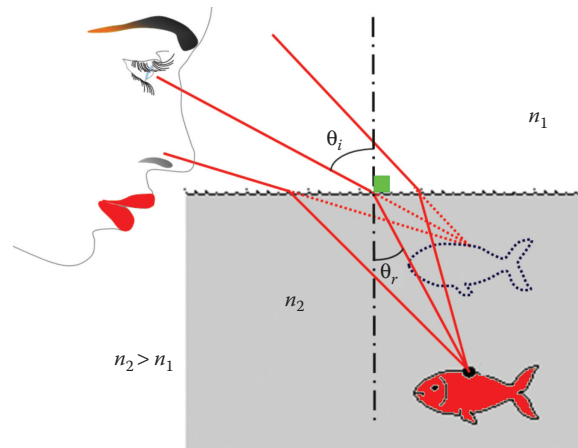


Figure S.78 Snell's Law.

Socrates (469–399 BC)

[general] Philosopher from Greece, born in Athens. Recognized as one of the architects of analytical thinking, sciences and western philosophy (see [Figure S.79](#)).

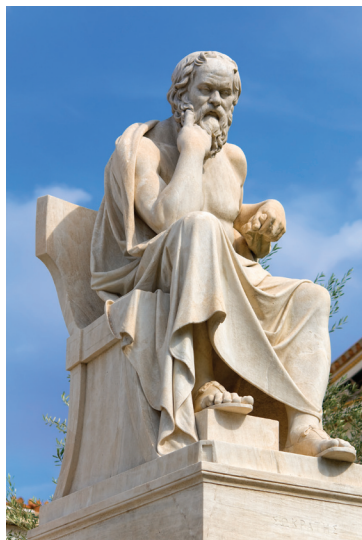


Figure S.79 Artist representation of Socrates (469–399 BC).

Soddy, Frederick (1877–1956)

[atomic, chemical, nuclear] Physicist and radiochemist from Great Britain. Soddy introduced the term ISOTOPE, explaining the RADIOACTIVE DECAY of certain ELEMENTS that have the same location in the periodic table, in collaboration with ERNEST RUTHERFORD (1871–1937). Fredrick Soddy received the Nobel Prize in Chemistry in 1921 for his contributions in the understanding of the RADIOACTIVITY in chemical substances and the pertaining chemical configuration (see [Figure S.80](#)).



Figure S.80 Frederick Soddy (1877–1956). (Courtesy of University of Glasgow, *College Courant*, the journal of the University of Glasgow Graduates' Association, no. 64, March 1980.)

Sodium ($^{22}_{11}\text{Na}$)

[biomedical, chemical, nuclear] Metallic element (Latin: Natrium). Silver white ALKALI METAL. The HUMAN BODY in particular uses sodium to mitigate BLOOD PRESSURE as well as blood volume. Sodium also serves as a catalyst in the operation of muscles and provide nerves with a chemical means to maintain a trans-membrane potential and form an ACTION POTENTIAL. Sodium was discovered in 1807 by HUMPHRY DAVY (1778–1829) as the result of the ELECTROLYSIS of sodium hydroxide (inorganic compound, commonly found as caustic soda; lye. Frequently used in detergents). Sodium is abundant on EARTH and ranks sixth as the most liberally available substance, most commonly found in “table-salt”: sodium chloride. Sodium has

a very prominent yellow spectral line (D line at $\lambda = 589.3$ nm), which is sometimes used in street LIGHT illumination (*see* SODIUM, ENERGY LEVELS) (*see* Figure S.81).



Figure S.81 Sodium crystal.

Sodium chloride (NaCl)

[biomedical, chemical] SALT, compound that easily dissociates into the ions Na^+ and Cl^- in water, certain alcohols and glycerol to name a few. Major component of biological system, specifically human BLOOD, and hence used as constituent in buffered Saline SOLUTION for infusion during hospitalization. As for most salts our tongue has specific sensors for metallic salts (including and highly sensitive for NaCl), as one of the five main “flavors.”

Sodium cooled reactor

[nuclear] Nuclear reactor power plant that uses liquid Sodium as a coolant for the REACTOR process. Nuclear power plants use coolants to make the heat generated from the core available for power generation in steam turbines. Coolants also maintain a controllable pressure within the core of the reactor (see NUCLEAR REACTOR) (see Figure S.82).

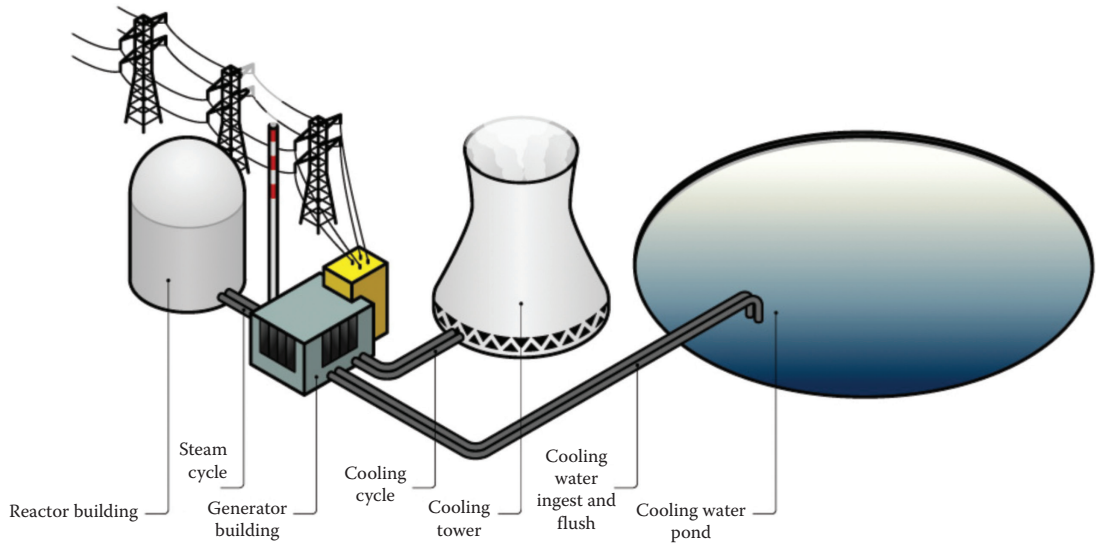


Figure S.82 Nuclear reactor diagram with a heat exchange between the internal sodium cooling and the external water cooling driving the steam reactors. One of the alternatives is a pressurized “heavy” water internal cooling.

Sodium iodide detector

[nuclear] Device used to measure radiation based on “scintillation” principles resulting from interaction of RADIOACTIVE DECAY with the ENERGY bands in the sodium iodine crystal, which generate photons that pass through a photomultiplier for gauging the MAGNITUDE of the incident radiation. Generally this type of detector ranks behind the gas-filled detector, which uses IONIZATION for detection, measured by an ANODE in a current meter set-up.

Sojourner

[astrophysics/astronomy, general] Robotic MARS rover delivered by the Pathfinder spaceship in 1997 used for extensive Mars exploration (see [Figure S.83](#)).

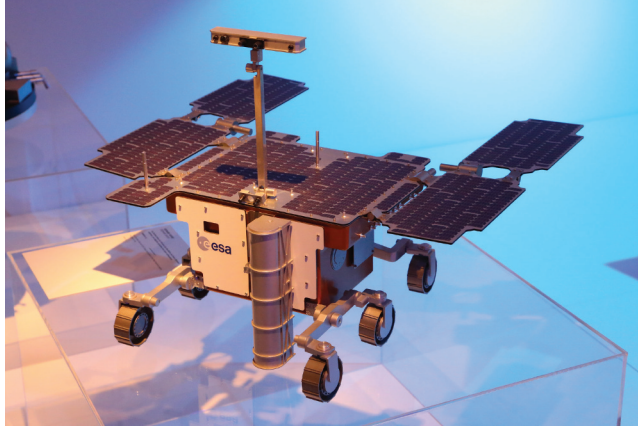


Figure S.83 Sojourner.

Solar power

[thermodynamics] The systematic use of the LIGHT from the SUN to produce ELECTRICITY resulting from the PHOTOELECTRIC EFFECT. The photoelectric effect was described by Alexandre-Edmond Becquerel (1820–1891), a physicist from France, observed the photoelectric effect in 1839. Solar panels are used in various sizes to power portable gear during camping trips or supply an entire city of all the electricity requirements for normal operation. To date the best ENERGY conversion for solar cells is in the order of 24%. Solar power relies on the photoelectric effect for the generation of electricity. The Romans built glasshouses in the thirteenth century. The first documented solar collector was built in 1767 by the scientist Horace-Bénédict de Saussure (1740–1799) from Switzerland. Horace de Saussure developed large cone shaped collectors that used ammonia which would boil to perform work acting as a locomotion or perform

refrigeration. In 1861 Auguste Mouchout (1825–1911) developed a steam ENGINE powered by solar energy alone (see [Figure S.84](#)).



(a)



(b)

Figure S.84 Solar power: (a) solar farm and (b) solar-powered airplane, combining the solar energy to power flight in addition to the aerodynamics of the design of the plane and the mechanical integrity to withstand shear stress from wind turbulence. (Courtesy of Solar Impulse®, Lausanne, Switzerland.)

Solar system

[computational] Galactic arrangement of the planets orbiting our SUN, from the inside out, Mercury, VENUS, EARTH, MARS, JUPITER, SATURN, Uranus, Neptune, and Pluto. Earlier models were GEOCENTRIC, the most well described of this kind was by PTOLEMY (approximately 90–168 AD) published around 140 AD. The first attempt to account for the deviations in the Ptolemy model by placing the Sun in the center of the planetary revolutions was by the “Polish”/German (Prussia) scientist NICOLAUS COPERNICUS (1473–1543; Niclas Koppelnigk) suggesting a HELIOCENTRIC model, published in 1543 (“*De Revolutionibus Orbium Coelestium*”), but presented the idea in the late 1400s to early 1500s. Based on the observations by the German astronomer and mathematician TYCHO BRAHE (1546–1601) in the late 1500s the foundation was

made for a rigorous description of a solar centered planetary system, introduced by JOHANNES KEPLER (1571–1630) in 1609, using the unpublished data from Tycho Brahe (see [Figure S.85](#)).

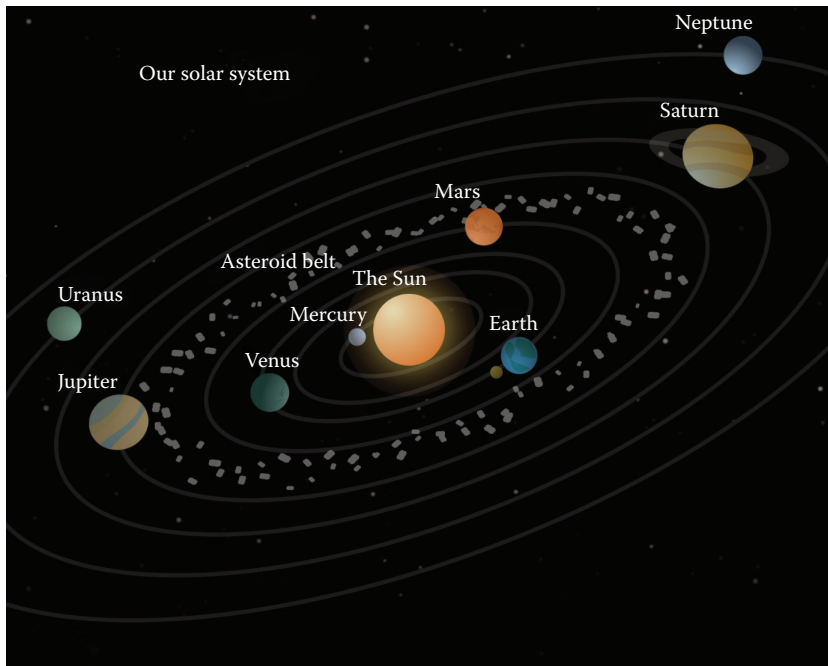


Figure S.85 Solar system.

Solar therapy

[biomedical, chemical, optics] Use of sun-light to treat SKIN disorders. Even though the beneficial effects of sunlight to the body for general health as well as for therapeutic applications to skin diseases (e.g., psoriasis, acne) and general benefits to mood were known for millennia by the Egyptians, healers in India and China the scientific description was provided by NIELS RYDBERG FINSEN (1860–1904). The use of sunlight later progressed on to artificial light-sources in PHOTODYNAMIC THERAPY.

Solar wind

[astrophysics/astronomy, general] RADIATION pressure that exerts a force on ionic material, charged PARTICLE content, primarily resulting from the SUN due to the high radiance. The pressure inflicted by electromagnetic radiation can be defined based on absorption or REFLECTION, where the impulse of reflection is twice as large, respectively expressed as $P_{\text{solar}} = S/c$, where $\vec{S} = (1/\mu_0)\vec{E} \times \vec{B}$ is the Poynting vector (equivalent power flux), $\vec{E}$ the electric field, $\vec{B}$ the MAGNETIC FIELD, $\mu_0 = 4\pi \times 10^{-7}$ H/m the permeability of free space, and c the speed of LIGHT; alternatively $P_{\text{solar}}^{\text{reflect}} = 2(S/c)$. The solar wind will divert the direction of the ION tail (ionized gasses etc.) of comets, but will have only minor effect on the dust tail which will be in-line with the path of the COMET. Generally, the solar wind is much greater than the gravitational attraction force.

Solenoid

[general] Wound helical coil that can generate a magnetic field ($\vec{B}$) when a current is applied through the wiring that makes the windings. The MAGNETIC FIELD distribution of a solenoid is very uniform and is described as a function of location as $\vec{B} = [\mu_0(N/\ell)I]/2(\sin\theta_2 - \sin\theta_1)\vec{j}$, $\mu_0 = 4\pi \times 10^{-7}$ H/m the permeability of free space, I the MAGNITUDE of the current, $\vec{j}$ the unit vector for the current direction, θ_1 and θ_2 respectively the ANGLE with the normal to the coil with respect to a point in free space where the magnetic field magnitude is

desired to be known, from either edge of the coil respectively, and N/ℓ the number of windings/turns N per length ℓ of the solenoid. Solenoids are often used to open and close by moving a METAL object through the core of the coil as a result of the attraction force described by AMPÈRE'S LAW, defining the magnetic field strength as a function of the applied current and the number of windings as a function of DISTANCE. The force resulting from a magnetic field on a charge is $F_{\text{magn}} = q\vec{v} \times \vec{B}$, with q the ELECTRIC CHARGE, $\vec{v}$ the velocity of the charge, which can be applied to EDDY CURRENT for ferromagnetic materials (see Figure S.86).

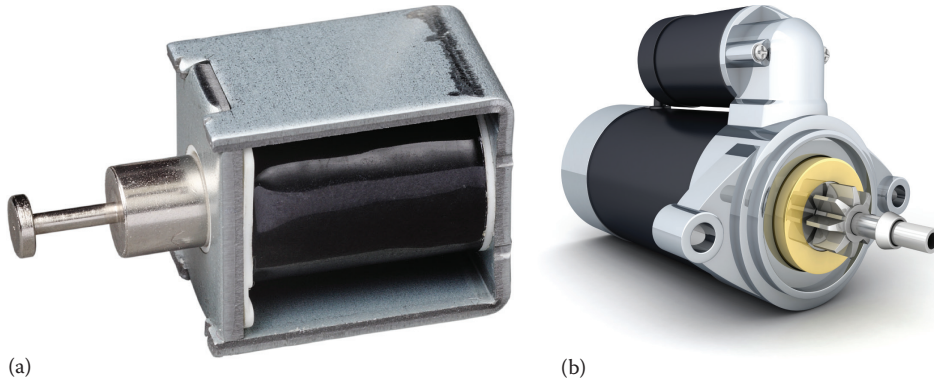


Figure S.86 Solenoid. (a) Simple solenoid as used on an automatic door-lock and (b) automobile starter with solenoid to "throw" the rotating starter gear into the teeth of the fly-wheel of the engine.

Solid angle

[computational, nuclear] The solid angle from a point O towards a surface area A with curvature C can be described by connecting the edges of the area A to the point of reference O . When a sphere is placed around the reference point O with radius r , this sphere will SLICE through the cone of lines connecting to the edge of area A . The MAGNITUDE of the surface area carved out by the cone has an area A' . In general the area of a sphere is $A = 4\pi r^2$. The area A' is also proportional to r^2 this way, since it is a fraction of the total surface area of the sphere. The solid angle Ω that is enclosed by the cone originating in O is defined as $\Omega = A'/r^2$. The units of the solid angle: Ω are steradians. The solid angle is independent of the shape of the surface, since it only demarcates the outline in space and relief has no impact on that, and it does not depend on the radius to the reference point (see Figure S.87).

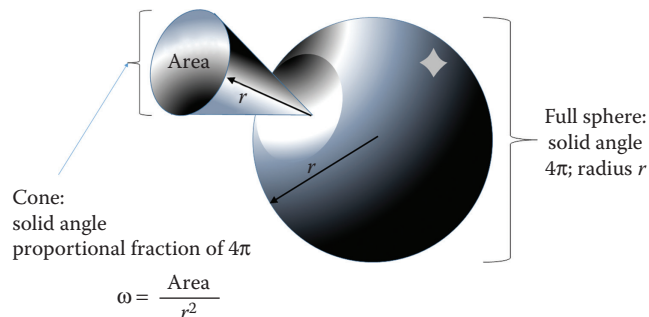


Figure S.87 Solid angle.

Solid form of aggregation

[thermodynamics] The solid phase, one of the four states of a composite material or ELEMENT: gas, LIQUID, solid, and PLASMA.

Solidification

[thermodynamics] The process of converting a medium into solid state. Generally achieved by lowering the temperature below the FREEZING point.

Solid-state

[atomic, nuclear, thermodynamics] Sometimes also referred to as condensed MATTER, depending on the thermodynamic ENERGY balance.

Solid-state physics

[atomic, nuclear, thermodynamic] Branch of condensed MATTER physics dealing with the investigation of the properties of solids by means of for instance crystallography, QUANTUM MECHANICS. Additional mechanisms involve electromagnetism and more generally material science; which deals with mechanical properties such as hardness, elastic modulus, thermal conduction, electrical conductivity, and more under different thermodynamic and chemical conditions.

Soliton

[acoustics, computational, fluid dynamics, mechanics, quantum] A WAVE that acts as a PARTICLE. A solitary wave, which by definition are nonlinear in nature. Particular reference as a SOLUTION to the KORTEWEG—DE VRIES EQUATION (see [Figure S.88](#)).

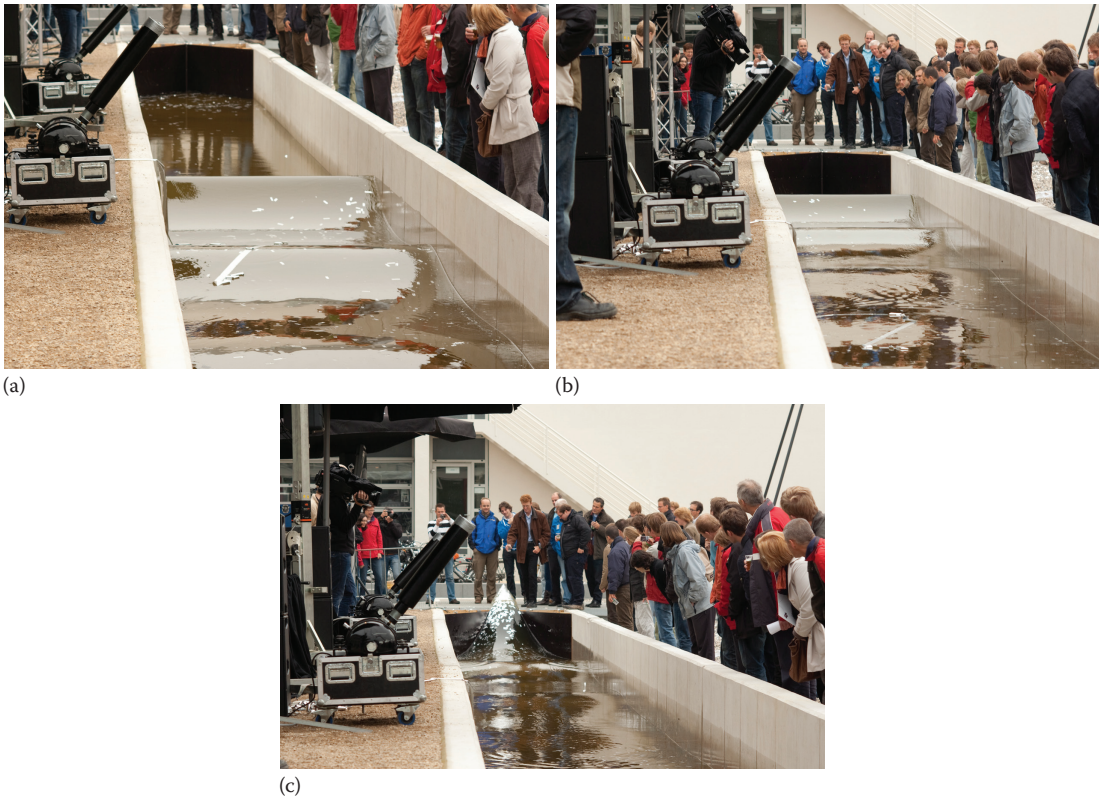


Figure S.88 (a–c) Soliton, water wave progression (excerpts). (Courtesy of Onno Bokhove, Wout Zweers, with Anthony Thornton; University of Technology Twente, Enschede, the Netherlands.)

Solstice

[astrophysics/astronomy, general, geophysics] The astronomical events where the axis of the EARTH cantilevers to position the SUN directly over either the Tropic of Capricorn in the southern hemisphere marking the onset of winter or the Tropic of Cancer in the northern hemisphere, indicating the beginning of summer for the northern hemisphere. This indicates respectively the winter and summer solstice (see Figure S.89).

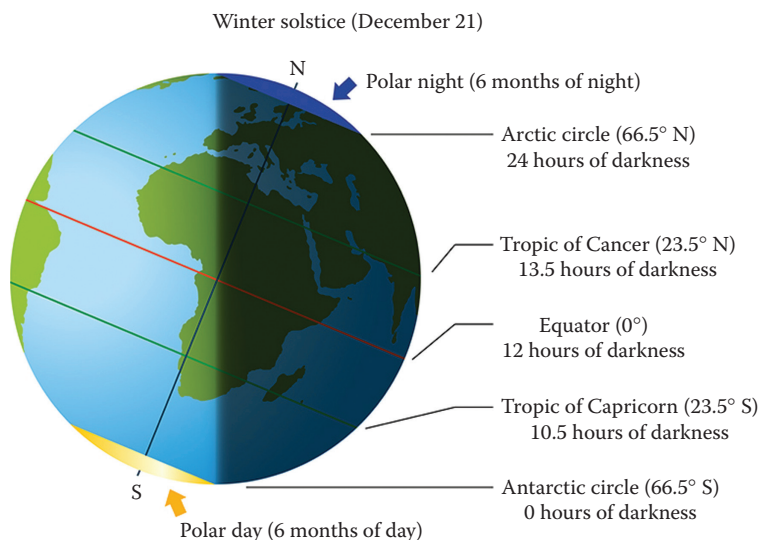


Figure S.89 Solstice.

Solute

[thermodynamics] Medium mixed-in with a SOLVENT to form a SOLUTION. The solute is dissolved in the solvent. The solute can be in the same phase (FLUID or GAS) as the solvent but has a smaller quantity either in mass or in volume.

Solution

[chemical, thermodynamics] Mixture of at least two substances, one usually a LIQUID, the other can be liquid, or solid, if the liquid is in gaseous form the SOLUTE (mixed-in substance, in this case identified by a smaller quantity) can also be a GAS. The mix of substances will be homogeneous. The solute can remain intact or dissolve into the ionic component that make the component, the most well-known example is the solute NaCl (SALT) in water. Solutions in water are referred to as aqueous solutions. The concentration of the solution is the quantity of the solute with respect to the solute, expressed in gram per liter or MOLE per liter. A saturated solution has reached the limit by which the solute's ions or molecules can be covalently bound to the solution and the solute will precipitate and condensate or solidify on the WALL of the container, primarily the bottom for solid solutes. The SATURATION or the amount of solute that can be dissolved in the SOLVENT is dependent on the temperature of the solvent. Cooling a solution can (and will, depending on the temperature range; some solutions have a very broad range of stable BINDING ENERGY balance) result in condensation of the solute. An IDEAL SOLUTION will adhere to RAOULT'S LAW; the partial (e.g., vapor-) pressure of a solution of a nonvolatile mixture is equal to the partial/VAPOR PRESSURE of the pure constituent/solvent at that temperature multiplied by its mole fraction. Raoult's law was introduced in 1882 by FRANÇOIS-MARIE RAOULT (1830–1901), a chemist from France.

Solvent

[thermodynamics] Liquid medium that allows MIXING with other medium LIQUID or solid or GAS to form a SOLUTION.

Somesthesia

[biomedical, mechanics] The ability to detect stimuli internal and external to the body. The stimuli can be thermal, mechanical, or even painful. This mechanism is part of the senses and is primarily serving the need for protection of the biological entity for instance is the stimulus sufficiently strong to damage tissues. An additional purpose of somesthesia is general experience of one's surroundings and the associated enjoyment or disgust based on the mental processing and predetermination.

Sommerfeld, Arnold Johannes Wilhelm (1868–1951)

[atomic, computational, fluid dynamics, general, nuclear] Physicist and mathematician from Germany. Arnold Sommerfeld provided significant contributions to the theoretical field of quantum PHYSICS and the description of atoms. He introduced the azimuthal QUANTUM NUMBER with respect to atomic wavem-echanics, the second quantum number (ℓ), as well as the SPIN quantum number, the fourth quantum number (s). Arnold Sommerfeld was a contemporary of, and collaborator with Léon Brillouin (1889–1969). He also introduced the FINE-STRUCTURE CONSTANT, and pioneered X-RAY wave theory (see [Figure S.90](#)).



Figure S.90 Arnold Johannes Wilhelm Sommerfeld (1868–1951).

Sonic boom

[general] Acoustic WAVE generated as the result of the oscillating source overpassing the pressure WAVEFRONT when traveling at velocity exceeding the speed of SOUND with respect to the FLUID. The pressure wave can be described by the Rankine-Hugoniot relation as $P_2/P_1 = ([(\gamma_c + 1)/(\gamma_c - 1)](\rho_2/\rho_1) - 1) / ([(\gamma_c + 1)/(\gamma_c - 1)] - (\rho_2/\rho_1))$, where $\gamma_c = c_v/c_p$ the ratio of SPECIFIC HEAT under constant volume to the specific heat under constant pressure, P the pressure, and ρ the density in the respective locations (i). For ideal gasses (e.g., atmospheric AIR) this transforms under velocities (v) in the Mach range (exceeding the speed of sound) to: $(P_2 - P_1)/P_1 = 2[\gamma_c / (\gamma_c + 1)](Ma^2 - 1)$. See MACH NUMBER ($Ma = v/v_{\text{sonic}} = \sqrt{Re} \times Wi = v\sqrt{\rho/E}$; Young's modulus (E), also called Elastic modulus. In the definition

the following are also used: Re the REYNOLDS NUMBER and Wi the Weisenberg number) (see SHOCK-WAVE and MACH-CONE) (see Figure S.91).



Figure S.91 Sonic boom of airplane flight past, with condensation illustrating the rarefaction of the Mach cone.

Sonogram

[acoustics, biomedical, general, mechanics] Image obtained by ULTRASOUND imaging, primarily in medical diagnostics, also referred to as ULTRASONOGRAM. The IMAGE is formed by reflected PRESSURE WAVES that result from piezoelectric transducers placed in contact with the object under investigation. The trajectory of the pressure waves obeys SNELL'S LAW of REFLECTION and REFRACTION and can be collected at the same location where the pressure waves are generated. The ultrasound TRANSDUCER will intermittently emit pressure WAVE, and in the un-powered state there will be a quiet period in which the same transducer is used to detect the returning pressure wave. The time delay (Δt) between emission and detection will provide the DISTANCE (d) traveled from the source to the point of reflection based on the SPEED OF SOUND (v) defined by $d = v \times \Delta t$. Using the signals collected from various external positions correlated over time can be used to reconstruct the two-dimensional pattern of boundaries of mismatched INDEX-OF-REFRACTION, more specifically mismatched ACOUSTIC-IMPEDANCE resulting from layers of media. This process is accomplished by a sweeping or PHASED-ARRAY transducer. A linear transducer will generate a two-dimensional SLICE, which can be expanded using IMAGE REGISTRATION techniques to provide a lateral EXPANSION to the scan resulting from redirection of the pressure wave source orientation. Alternatively, a two-dimensional ultrasound array can provide a three-dimensional image virtually instantaneously. Ultrasound attenuates rapidly in a gaseous environment, which requires that the contact between the object and the transducer is directly

mechanical. ACOUSTICAL IMPEDANCE matched, direct mechanical contact is often accomplished by the use of an IMPEDANCE MATCHING gel placed between the ultrasound source and the test object. One of the primary sonographic applications is in tracking the growth rate of a fetus in the womb of a WOMAN. The pressure waves supposedly form minimal risk to the unborn child, whereas X-RAY or other IONIZING RADIATION or high power forms of ELECTROMAGNETIC RADIATION (i.e., MRI) can interfere with the development of the fetus (see Figure S.92).

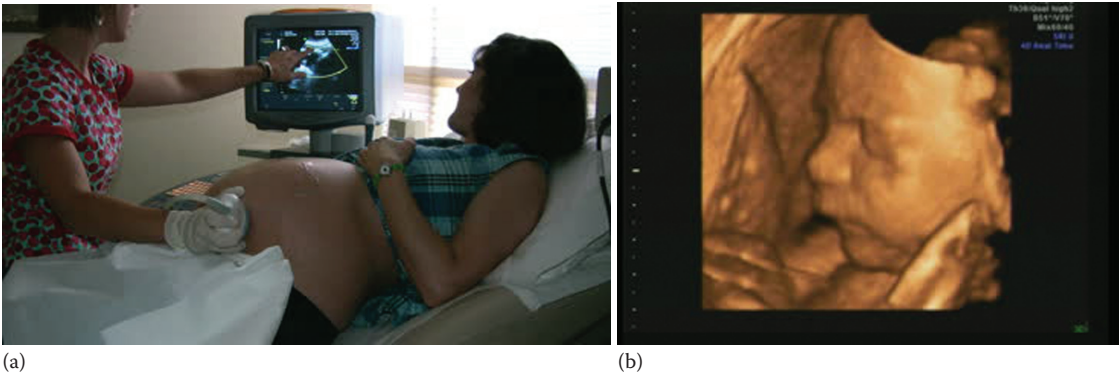


Figure S.92 Sonogram. (a) Scanning motion over belly of pregnant woman and (b) three-dimensional reconstructed ultrasound image of baby in womb.

Sonography

[acoustics, general, imaging] See ULTRASOUND IMAGING.

Sonohysterography

[acoustics, general, imaging] Minimally invasive ULTRASOUND technique applying saline infusion. The saline forms a “impedance matching” condition, since AIR or GAS in human cavities creates significant ULTRASONIC IMAGING distortions due to scatter and attenuation. Specifically used to IMAGE the inside of a woman’s uterus. Saline is injected into the uterine cavity, by which means it is distended or enlarged. The saline impedance matching provides clear visualization of the outline of the endometrium (i.e., the lining of the cavity of the uterus), revealing polyps.

Sonoluminescence

[acoustics, energy] Specifically BUBBLE Sonoluminescence, the process of CAVITATION after bubble collapse where the acoustic ENERGY is converted in high-temperature atomic thermal agitation or even PLASMA formation and inherent emission of electromagnetic RADIATION.

Sørensen, Søren Peder Lauritz (1868–1939)

[chemical] Chemist from Denmark responsible for the initial concept of acidity and alkaline behavior of LIQUID, expressed as pH: $\text{pH} = -\log_{10} H^+$, based on the hydrogen ION concentration ($[H^+]$). This was later revised to use the hydrogen ion activity (see [Figure S.93](#)).



Figure S.93 Søren Peder Lauritz Sørensen (1868–1939) in 1918; photograph by Julie Laurberg (1856–1915) and Franziska Gad (1873–1921)—Royal Library, Copenhagen, Denmark.

Sound

[acoustics, fluid dynamics, general] Mechanical longitudinal waves generally considered operating in the frequency range 20–20,000 Hz. Sound is primarily acquired by the EAR (in both mammals and non-mammalian species), however the entire biological body is sensitive to mechanical vibrations and can sense sound COMPRESSION WAVES. Sources are vibrating solid objects, such as the vocal cords, GUITAR string and gaseous expansions such as electric spark discharges (e.g., LIGHTNING) and contractions such as during endothermic and exothermic chemical reactions. Sound can be recorded by electronic devices as well as mechanical means (e.g., needle attached to resonant fork carving pattern in for instance vinyl and wax) (*also see* HEARING). Sound is identified by the SPECTRAL CONTENT. Since sound devices will generate a FUNDAMENTAL FREQUENCY with associated higher HARMONICS which creates a SPECTRAL PROFILE. For instance in a string the fundamental frequency is directly correlated to the tension in the string, the cross-sectional dimension, the material(s) (certain strings are coaxially composed of various materials with specific structural characteristics, such as weave, braid, solid, etc.) and the length of the string. Sound has specific applications in music which has its own detailed phenomenological descriptions. Musical sound is denoted by splitting the spectral range in frequency interval such as octaves (from the Greek), which describes doubling the frequency in each step (i.e., fundamental to first harmonic = 1:2); in case the frequencies of two respective waves relate as 2:3 the ratio is called a perfect fifth *or* “quint” (e.g., a musical instrument can be tuned in “quint” setting), equivalently the ratios are segmented as: 3:4 = fourth *or* quart; 4:5 = major third *or* great tert; 5:6 = minor third *or* small tert, 3:5 = major sixth *or* sext; 8:9 = major second; 9:16 = minor seventh; 8:15 = major seventh and the 12th “note” 15:16 = minor second. All these tuning modes are segmented in six consecutive triads, building a 12 note chromatic scale as developed in the eighteenth century. This scale is also referred to as the Helmholtz pitch notation, developed by the German physicist HERMANN VON HELMHOLTZ (1821–1894). The 12 note mechanism was devised to build up a musical sequence using just one ratio, exemplified by the Thomas Young’s tuning formula (also known as Thomas Young’s 1799 well temperament). This supposedly has the advantage of making modulating between keys possible, however this aspect ratio segmentation does not hold exact. Two other segments were later added,

called tritons: 5:7 and 7:10. The current theoretical execution of the OCTAVE is thoroughly described in the works of Praetorius in 1619 (see [Figure S.94](#)).

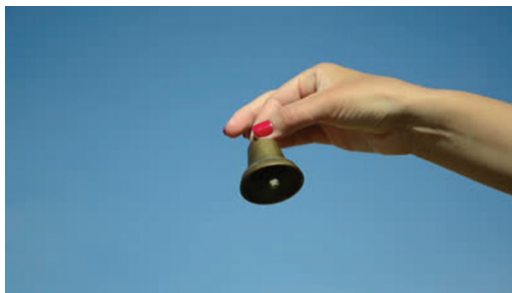


Figure S.94 Examples of the principle of sound.

South geographic pole

[general] See **GEOGRAPHIC SOUTH POLE**.

South magnetic pole

[general] See **MAGNETIC SOUTH POLE**.

Speaker

[acoustics, electronics, fluid dynamics, mechanics] See **LOUDSPEAKER**.

Special theory of relativity

[general, nuclear, quantum] See **THEORY OF RELATIVITY**.

Specific heat

[nuclear] ENERGY stored in lattice vibrations calculated from the Debye model is providing one specific aspect of the specific heat (C_v) = $(12\pi^4/5) N_A K_B (T^3/T_D^3)$, where $T_D = \hbar \nu_D/k$ is the Debye temperature; ν_D is the Debye frequency; $K_B = K = 1.38064852(79) \times 10^{-23}$ J/K is the Boltzmann constant; $N_A = 6.022140857(74) \times 10^{23}$ mol⁻¹ is the Avogadro constant; $C = \varepsilon T^{3/2}$, the low temperature “spin-wave” (MAGNETIC) specific heat, with T is the temperature, and ε is the ferromagnetic Debye coefficient; $C_e = \gamma T_e$ is the electronic heat capacity, with γ the reciprocal of the “RELAXATION TIME,” and T_e the “electron temperature” for the LATTICE vibrations. The total specific heat expression is as follows: $C = \gamma T + \varepsilon T^{3/2} + \beta T^3$ + correction, the correction will account for environmental variables and boundary conditions.

Specific heat (c_{sp})

[biomedical, general, mechanics, quantum, thermodynamics] The amount of heat that needs to be added to 1 g of material in order to raise the temperature of the material by 1 K, or sometimes also regarded as 1°C, to maintain accuracy in units: $c_{sp} = Q/m\Delta T$, describing the HEAT (Q) required to change the TEMPERATURE (T) of a MASS (m) by 1 K. The majority of this ENERGY is applied to increase the INTERNAL ENERGY with a rudimentary amount pertaining to work. The work effort is greater for heating under constant pressure than under constant volume, which applies primarily to gasses. Under very high temperature conditions the specific heat times the ATOMIC WEIGHT of all the respective chemical constituents is nearly constant, which is referred to as the LAW OF DULONG AND PETIT. This constant specific heat (“atomic heat”) results from the fact that at high temperatures the internal energy of atoms becomes approximately constant. This temperature phenomenon can be explained with QUANTUM THEORY.

Specific heat capacity (c_{sp})

[general] See **SPECIFIC HEAT**.

Specific resistance

[biomedical, electronics] The electrical RESISTANCE of a material with a length of 1 m and a cross-sectional area of 1 cm², this value is a characteristic value for the material. The specific resistance for copper at 18°C is 0.0000017 Ω .

Specific viscosity

[fluid-dynamics, mechanics] See VISCOSITY, SPECIFIC.

Specific weight

[general] The relative weight of a material/substance with respect to the weight of an equal volume of water at 4°C.

Spectroscopic ellipsometry

[imaging, material sciences, optics, solid-state] Diagnostic method for thin-film thickness determination as well as analyzing the location-specific chemical composition and film homogeneity. The spectroscopic analysis relies on polarization sensitive measurements of reflected electromagnetic RADIATION from interfaced between various layers of media, hence yielding the complex index-of-refraction of the respective media the LIGHT has traversed. Spectroscopic ellipsometry can be single-wavelength, which employs a MONOCHROMATIC LIGHT source, or multiwavelength. Ellipsometry determines the change in polarization of the light that is reflects from the layers of a stacked medium or from the transmitted light through a layer material structure. The POLARIZATION is generally defined by the relationship $\rho_{\text{pol}} = \tan(\Phi)e^{i\Delta}$. The polarization change is represented by means of the determination of the an AMPLITUDE ratio, Φ , as well as the PHASE difference, Δ , based on the complex index-of-refraction. The “ellipsometry” is defined by $\langle \tilde{\epsilon} \rangle(\lambda) = \sin^2(\vartheta) \left[1 + \tan^2(\vartheta) \{ (1 - \rho_{\text{pol}})/(1 + \rho_{\text{pol}}) \}^2 \right]$, which technically is a function of wavelength (λ) hence the spectral aspect. Furthermore, the process uses the fact that the index-of-refraction can be described under the Cauchy or Sellmeier relationship as $n(\lambda) = A + (B/\lambda^2) + (C/\lambda^4)$. The index of refraction is directly linked to the DIELECTRIC permittivity and follows the Kramers–Kronig description relating the dielectric permittivity to the molecular ENERGY configuration, in addition to being confined through SNELL’S LAW. The measured quantities are a function of the optical properties and thicknesses of individual material layers. Ellipsometry is primarily used to determine film thickness with the added benefit of identification of optical constants, thus providing details about the composition of each layer in particular DOPING concentration. Ellipsometry provides the sensitivity necessary to measure nanometer-scale layers, in particular used in quality control for wafer production in microelectronics. Next to this it is also applied to characterize crystallinity, and ROUGHNESS. Application of ellipsometry are found in analysis of flat panel display, biosensor, next to the optical coating industries such as solar polar construction.

Spectroscopy

[atomic, general, optics] In general spectroscopy stands for the spectral analysis of emitted light, and is equivalent in many ways to the PARTICLE phenomenon of COMPTON SCATTERING, both energetically and in spatial distribution. When intense MONOCHROMATIC LIGHT of frequency ν , illuminates a sample, it has been shown that light scattered from the sample not only contains RADIATION of frequency ν , but also weaker radiation of frequency $\nu \pm \nu'$. The weaker radiation components of the scattered light are known as the RAMAN SPECTRA. RAMAN SPECTROSCOPY is a measure of the frequency shift from the incident frequency. Assuming that incident photons carry sufficient ENERGY (directly linked to the wavelength; the shorter the wavelength—the higher the energy), a MOLECULE has the potential to absorb the energy from an incident PHOTON. The absorption results in an excited state for the molecule. The molecule prefers to revert to the lowest possible energy configuration, such as everything else in nature. However, instead of decaying with loss of all excitation energy by means of a full transition back down to the GROUND STATE, the molecule may prefer, based on energy conditions from neighboring molecules, make a transition down to another excited

vibrational state. The reemitted photon in this process depends on CONSERVATION OF ENERGY, and hence the (what is considered) scattered photon will be composed with slightly less energy with respect to the incident photon. The energy difference between the incident photon and the scattered photon matches the amount of energy required to bring the molecule in the higher energy excited vibrational state. The vibrational energy structure of the molecule can be gauged by determination of the frequency shift ν' with respect to the incident electromagnetic frequency ν . This vibrational energy structure (spectrum) for each molecule defines a fingerprint representing the molecular bonding within the specific sample. Several diagnostic techniques have been developed that are based on this specific and characteristic spectral profile by means of the spectral analysis of scattered light. Examples of certain diagnostic applications of Raman-Spectroscopy are for instance the in vivo analysis and characterization of chemical blood-gasses, next to BLOOD glucose sensing. Raman spectroscopy is frequently used in forensic sciences for the detection of toxic substances next to the comparison of sample with “culprit” in determination of cause and effect and quantification of probability of validity of correlations between various sources for the chemical constituents and mixtures. The latter technique can be called Raman spectroscopy assisted histology (see [Figure S.95](#)).

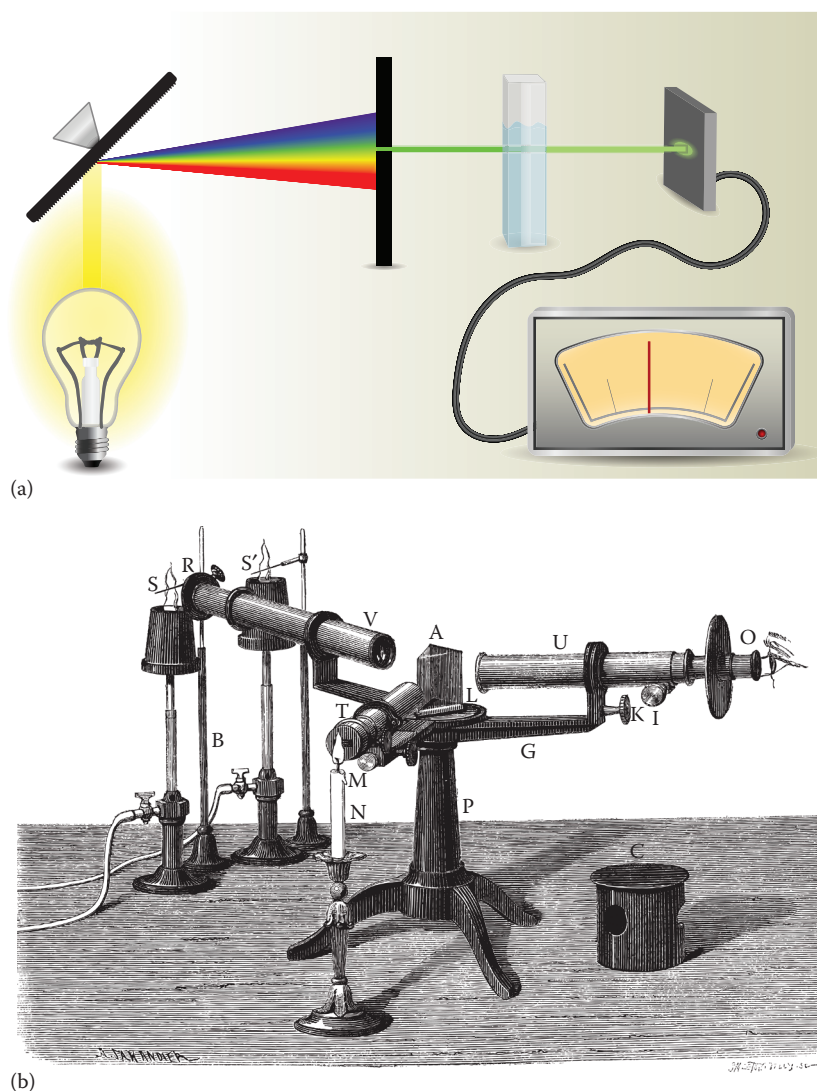


Figure S.95 (a,b) Spectroscopy.

Speed (v)

[general] Magnitude of the change in location as a function of time: $v = |dx(t)/dt|$, MAGNITUDE of the velocity vector. The time rate of displacement; DISTANCE moved per unit time. CGS unit: cm/s. The ANGULAR SPEED (ω) is the rate of change in the angular position (θ) of an object: ANGULAR VELOCITY: $\omega = |d\theta(t)/dt|$.

Speed of wave propagation in a confined liquid

[fluid dynamics] v_s , (FLUID DYNAMICS), speed of WAVE propagation in a confined liquid.

$v_s = \sqrt{(K/\rho)/(1 + (D/b)(K/E)\text{Const})}$, with the LIQUID flow density ρ , K the bulk modulus of the liquid with regard to compressibility, D the inside diameter of tube with wall-thickness b , E the Young's modulus of the flexible PIPE and Const a correction factor for dimensional and material factor affecting the speed of SOUND.

Spherical wave

[general, optics] $U(\vec{r}) = (A/r)e^{ik\vec{r}}$, where A a constant (i.e., AMPLITUDE), $k = 2\pi/\lambda$ the wavenumber, and $\vec{r}$ the vectorial DISTANCE to the source.

Sphygmomanometer

[biomedical, fluid dynamics] BLOOD PRESSURE sensing device based on application of external pressure in order to close off the blood-flow in the artery (specifically in the elbow of the arm) and subsequently reducing the external pressure. The principle relies on the pressure balance from the cuff applied to the tissue, where the pressure equilibrium ensures the sealing of the artery when the external pressure exceeds the internal pressure. The pressure inside the brachial artery is directly proportional to the applied pressure from the contractile MOTION of the HEART, the brachial artery is directly connected to the AORTA. As the pressure in the inflated cuff that is wrapped around the arm is reduced the pressure will reach a point where at the time of ventricular contraction the brachial pressure equates the applied pressure, which will be a function of the vascular health of the person as well as the heart function of the person under examination. At the high pressure equilibrium the SYSTOLIC PRESSURE will allow blood to flow under intermitted episodes, coinciding with the heartbeat. As the pressure in the cuff of the Sphygmomanometer is reduced even further at the low pressure an equilibrium with the DIASTOLIC PRESSURE will be reached, from which point onward (decreasing external pressure even further) the flow will be continuous. The sphygmomanometer was introduced in 1881 by Samuel Siegfried Karl Ritter von Basch (1837–1905) from Schechoslovakia/Austria (Prussian Empire) and refined by SCIPIONE RIVA-ROCCI (1863–1937) from Italy

with further refinements to the detection mechanism by the surgeon NIKOLAI KOROTKOV (1874–1920) from Russia in 1905. Also referred to as a Sphygmomanometer (*also see* KOROTKOFF SOUND) (see [Figure S.96](#)).

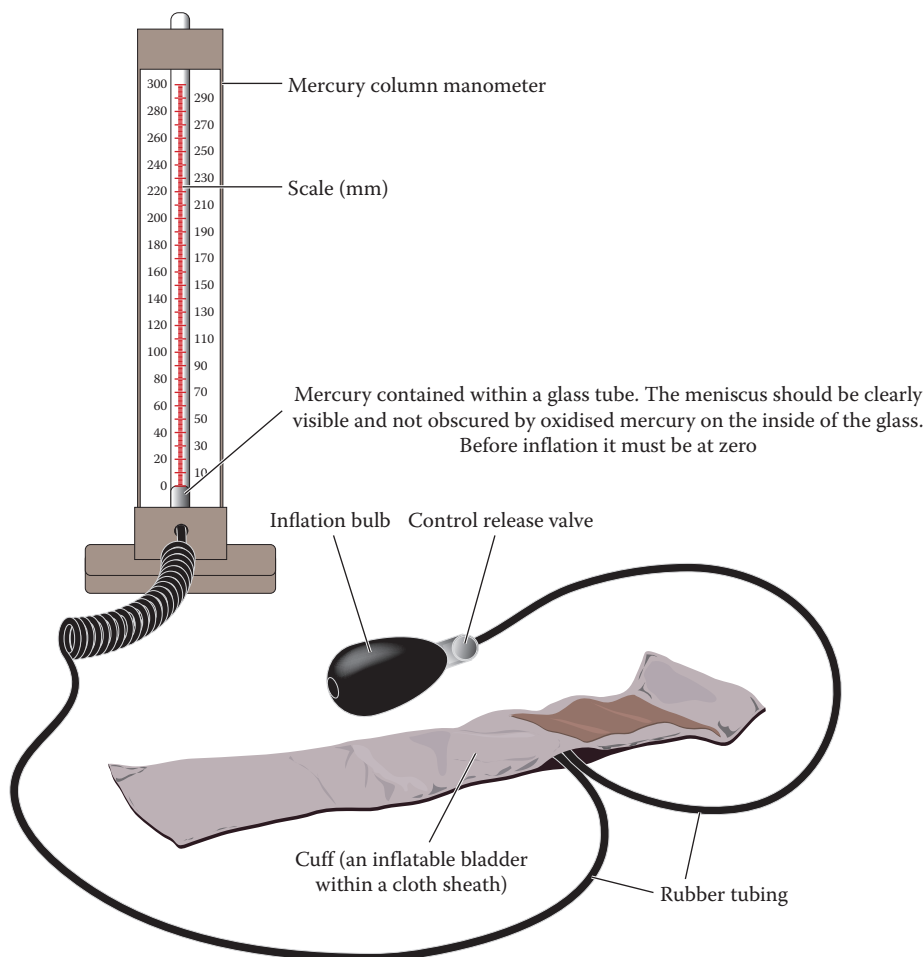


Figure S.96 Sphygmomanometer.

Spin

[atomic, general, mechanics, quantum, thermodynamics] Rotation of a solid object around its central axis. Examples of object with spin are a top, or a system of particles grouped together: electron constructed of ELEMENTARY PARTICLES, PROTON and NUCLEUS; next to the EARTH consisting of atoms and molecules. The rotation creates an angular momentum: $\vec{L} = I\vec{\omega}$, I the MOMENT OF INERTIA of the object with respect to the axis of rotation and $\vec{\omega}$ the angular velocity. The spinning MOTION presents a mechanism that counteracts a change in the ANGLE of the axis of rotation. This phenomenon is observed when the front wheel of a bicycle is lifted from the GROUND and made to rotate, while rotating there is the sensation of a torque in the opposite direction to the applied torque applied to turn the direction in which the wheel points. The angular momentum pointing perpendicular to the area of the wheel, pointing in the direction defined by the crotch-screw rule; following the rotation of the wheel with a crotch-screw will either move forward or backward from within the stopper in the wine-bottle. The angular momentum vector points in the direction of the advancement of the crotch-screw. The reactionary force resulting from the SPIN in response to the applied torque is defined through the right-hand rule, resulting in a torque in the opposite

direction with respect to the applied torque, making it difficult to turn the rotating wheel. Steering to the left generates a TORQUE (τ_F) to the right as a result of the change in orientation of the wheel as a function of time: $\tau_F = dL/dt$. This inherent property of the rotating (spinning) device for the basis for the uncanny and relentless stability of the GYROSCOPE. The first gyroscope was introduced in 1852 by JEAN BERNARD LÉON FOUCAULT (1819–1868) to illustrate the rotation by the Earth. Also, the inherent, intrinsic angular momentum of an atomic PARTICLE is identified by a QUANTUM NUMBER in modern atomic theory. The concept of “spin-up” refers to rotation from west to east, such as the earth’s rotation; in contrast “spin-down” refers rotation in the opposite angular direction. In atomic notation the concepts of spin-up and spin-down separates the energetic stages of two electrons in the same orbit, with identical BINDING ENERGY (based on the primary quantum number: n). For atomic notation the spin angular quantum number is s , with potential values of $s = +(1/2)$; $-(1/2)$. An object with spin exposed to external forces (torque) is generally subject to PRECESSION of the axis of rotation as well as NUTATION. The rocking and swaying motion under nutation is more broadly defined than precession, including for instance a wavy pattern embedded in the precession. The angular momentum for the spin of, for instance an electron in orbit with the HYDROGEN ATOM produces a MAGNETIC FIELD with magnetic angular momentum: $L_z = m_l \hbar$, m_l the MAGNETIC QUANTUM NUMBER and, $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK’S CONSTANT. The total orbital angular momentum in the Bohr model is defined by the ORBITAL ANGULAR MOMENTUM quantum number ℓ as $L = \sqrt{\ell(\ell+1)}\hbar$, $\ell = 0, 1, 2, \dots (n-1)$ (see Figure S.97).

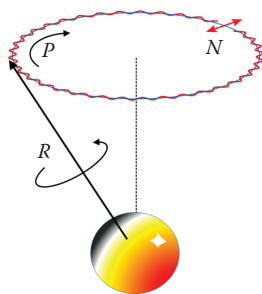


Figure S.97 Spin.

Spring force

[general, mechanics] Force (F) resulting from mechanical deformation of a solid object, primarily compression/extension but also TORSION (e.g., McPherson strut) as well as compression or EXPANSION of a GAS in a sealed container with a plunger (gas-spring or gas SHOCK-ABSORBER), but also electrostatic spring. For the solid object the force is directly proportional to the mechanical displacement (x) defined linearly by HOOKE’S LAW as $F = -kx$, where k is the spring constant. For the electrostatic spring the spring constant is defined as $k = -(CV_b^2/d)$, where C is the capacitance, d the CAPACITOR gap and V_b the bias voltage. For a gas-spring (with a moveable plunger) the spring constant can be described as $k = \rho_m(\partial P/\partial \rho)(\mathcal{A}^2/V_m)$, with ρ the gas density, V_m the mean volume (<https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/4560/research.pdf?sequence=3>) for high pressure as $k = PA/d$, with P the pressure, $\mathcal{A}$ the plunger-cross sectional area and d the displacement, however theoretically the frequency dependence will need to be incorporated for certain applications. For the volume of FLUID in a sound-pipe the spring constant is defined by

$k = \rho v_s^2 (A^2/V)$, where v_s is the speed of SOUND, A the cross-sectional area of the “organ pipe,” and V the volume of the device (see Figure S.98).

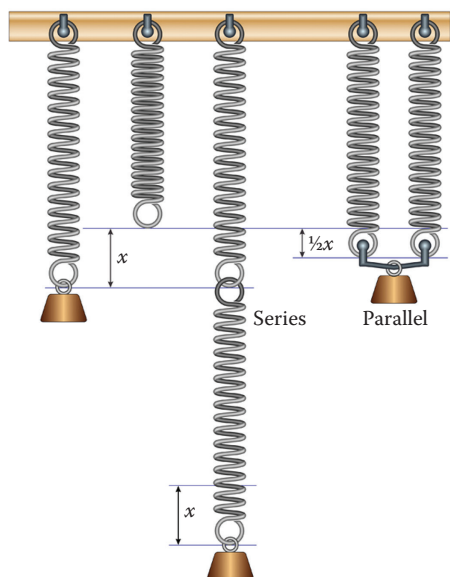


Figure S.98 Spring-force.

STANI

[acoustics] See SCANNING TOMOGRAPHIC ACOUSTIC MICROSCOPE.

Stanton number ($St = h/\rho v c_p = Nu_L/Re_L Pr$)

[energy, fluid-dynamics] Dimensionless number used for identification of the scale of HEAT TRANSFER to the thermal capacity of a FLUID, where h is the heat transfer coefficient, ρ the density, v the characteristic velocity, c_p the heat capacity, and Nu_L the Nusselt number, Re_L the REYNOLDS NUMBER and Pr the Prandtl number.

Stanton number, mass transfer ($St_m = h_m/v = Sh_L/Re_L Sc$)

[energy, fluid dynamics] Dimensionless number relating concentration differences to flow velocity, where h_m is the mass transfer coefficient related to the DIFFUSION rate, v the velocity, and Sh_L the Sherwood number, Re_L the REYNOLDS NUMBER, and Sc the Schmidt number.

Star

[astrophysics, atomic, energy, fluid dynamics, general, geophysics, nuclear] Galactic body that emits LIGHT and other electromagnetic RADIATION. The SUN is one of our most well-known stars and with the closest proximity for detailed investigation. The Sun radiates light resulting from proton-proton collision, forming a DEUTERON along with the emission of a NEUTRINO and a positive electron (positron). Stars can be quantified by size and ENERGY/surface temperature. The radiant emission: luminosity and surface temperature are generally directly proportional to the mass of the STAR. Examples of nomenclature in

star classification are: giant, super giant, QUASAR, and WHITE DWARF (dim, dense star near its end), and exploding star formations as novae and supernovae. Generally the life and death of stars can be described by a nuclear and a mechanical phenomenon. The nuclear aspect is the fact that the star gains its massive amount of energy and associated emission from NUCLEAR FUSION and NUCLEAR FISSION processes. The mechanical component is driven partially by the thermal gradient resulting in both convective mass and heat DIFFUSION. The nuclear processes eventually deplete the elementary constituents of the molten and gaseous amalgam resulting in an oscillatory behavior that changes character with the composition of the star. Pulsating stars are a clear and obvious example of this OSCILLATION phenomenon, whereas the process also takes place on smaller scales. Radial modes of oscillation are the most obvious and easily recognizable, however nonradial modes such as standing waves on the surface are also observed as well as running waves. The Sun has a standing WAVE on the surface with a period of 5 min, and other stars have radial waves with periods of days. Longer periods are also identified, and these are classified by the CEPHEID VARIABLES (see Figure S.99).



Figure S.99 Star. Galactic grouping of stars that was defined as the constellation Orion and our Sun.

Stark, Johannes (1874–1957)

[chemical, electromagnetism, general, solid-state] German physicist. Stark empirically verified the COMPTON EFFECT in 1909. Stark contributed to the explanation of the ENERGY splitting concept described by the Zeeman–Stark Effect, also described as the Star-effect. The work of Stark contributed to the basic

understanding of electron orbital structure and energy, chemical bindings and ATOMIC ENERGY structures (see [Figure S.100](#)).

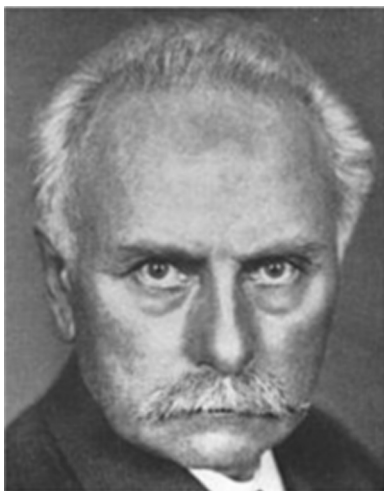


Figure S.100 Johannes Stark (1874–1957). (Courtesy of University of Wurzburg, Wurzburg, Germany.)

Stark effect

[computational, electromagnetism, energy, general, solid-state] See **ZEEMAN AND STARK EFFECT**.

Starling, Ernest Henry (1866–1927)

[chemical, fluid dynamics] Chemist from Great Britain. Ernest Starling introduced the OSMOTIC PRESSURE effects in a system separated by a semipermeable WALL. The principles are similar to those described by JACOBUS HENRICUS VAN'T HOFF (1852–1911) and are outlined under the STARLING'S LAW (see [Figure S.101](#)).

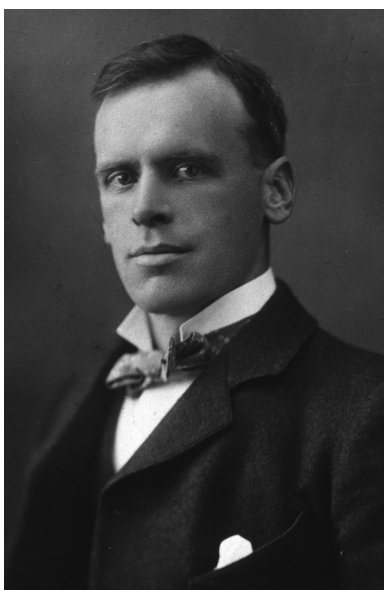


Figure S.101 Ernest Henry Starling (1866–1927). (Courtesy of National Library of Medicine, Bethesda, MD.)

Starling's law

[chemical, fluid dynamics] Hydrodynamic flow of colloid solutions separated by a membrane as defined by ERNEST STARLING (1866–1927) in 1915. Also called the Starling equation and the Frank–Starling law, based on the contributions by Otto Frank (1865–1944). Fluid MOTION between two compartments separated by a SEMIPERMEABLE MEMBRANE is the result of the combined hydrostatic and osmotic pressure. The OSMOTIC PRESSURE is described by the JACOBUS HENRICUS VAN'T HOFF (1852–1911) VAN'T HOFF EQUATION and in modified format by the MORSE EQUATION. The hydrostatic pressure in the flow and pressure process with respect to the CELL MEMBRANE is derived by means of the principles of the Bernoulli equation. The porosity of the membrane (L_p), also referred to as membrane permeability, directly influence the passage of the solutes, mainly placing restrictions on the size of the particles and molecules that can be exchanged to influence the osmotic pressure. The OSMOTIC PRESSURE (Π) is the result of the following components in the SOLUTE exchange, TONICITY (quantity of dissolved salts, proteins and other chemicals), hydrostatic pressure of hemoglobin, BLOOD colloids, interstitial fluid hydrostatic pressure (resulting from muscular compression and volume extension next to gradient in elevation with respect to the point of exchange), interstitial FLUID colloidal solution. The filtration pressure (P_{filter}) resulting from the combined osmotic pressure ($\Pi = iMRT$, where i is the dimensionless VAN'T HOFF FACTOR, M the molarity of the solutes, $R = 8.3144621(75) \text{ J/Kmol}$ is the UNIVERSAL GAS CONSTANT, and T the temperature of the reaction and SOLVENT) and hydrostatic pressure (P^{hydro}) over a surface area (A) is describes as (see Figure S.102)

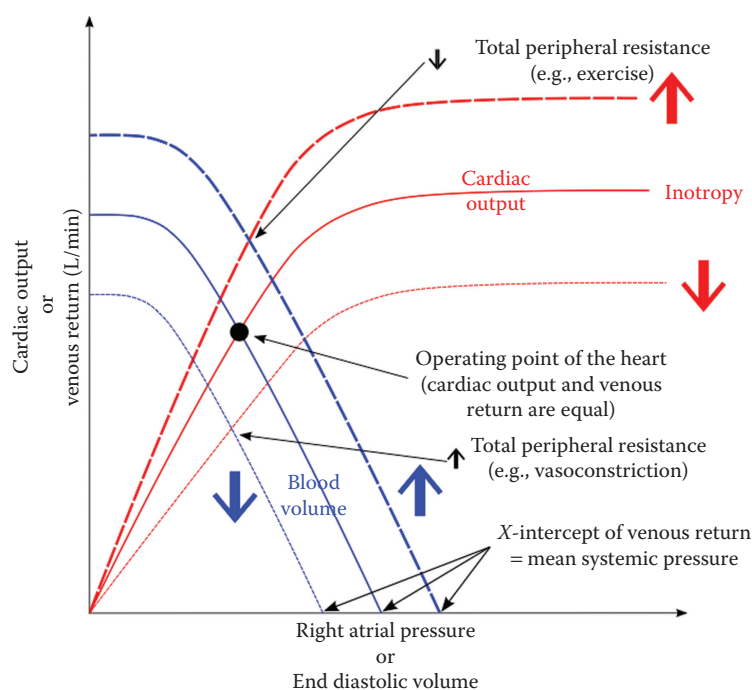
$$P_{\text{filter}} = \left\{ (L_p * A) * (P_{\text{capillary}}^{\text{hydro}} - P_{\text{interstitial}}^{\text{hydro}}) \right\} - \left\{ (A) * (\Pi_{\text{capillary}} - \Pi_{\text{interstitial}}) \right\}.$$


Figure S.102 Diagram illustrating the Frank–Starling law for the pump function of the heart, expressed as the cardiac function. The cardiac output, respectively the stroke volume, or stroke work are outlined by the vertical axis (y-axis). The horizontal axis (x-axis) generally denotes the end-diastolic volume. Alternatively, the x-axis can express the right atrial pressure, and sometimes is used to note down the pulmonary capillary wedge pressure as a parameter. The three curves indicate the change in preload, alternatively: afterload or contractility.

Static head

[fluid dynamics] For a PUMP, the maximum height the FLUID can reach under standard pump conditions. For a windmill used in drainage of low-lying areas (e.g., the Netherlands) the static head is approximately 1.5 m, which required placing these pumps in series with a moat separating two or more pump stages to overcome the technically feasible elevation of the LIQUID by the pump. Respectively, pumps used at drinking water wells can pump approximately against a static head of 20 m. Also known as hydraulic head. The static head is a pressure in liquid (most often water) column. This limitation can be overcome by using electric pumps in comparison to the use of windmills in the Netherlands to drain the low-lying areas north of Amsterdam as done by the hydraulic engineer from the Netherlands Jan Adriaanszoon Leeghwater (1575–1650) in 1607. A large water drain windmill in the Netherlands can pump approximately $38 \text{ m}^3/\text{min}$ against a static head of 1.3 m, such as used in the polders near Rotterdam, dating as far back as 1414. Note that windmill history can be traced back at least to seventh century Persia (see [Figure S.103](#)).

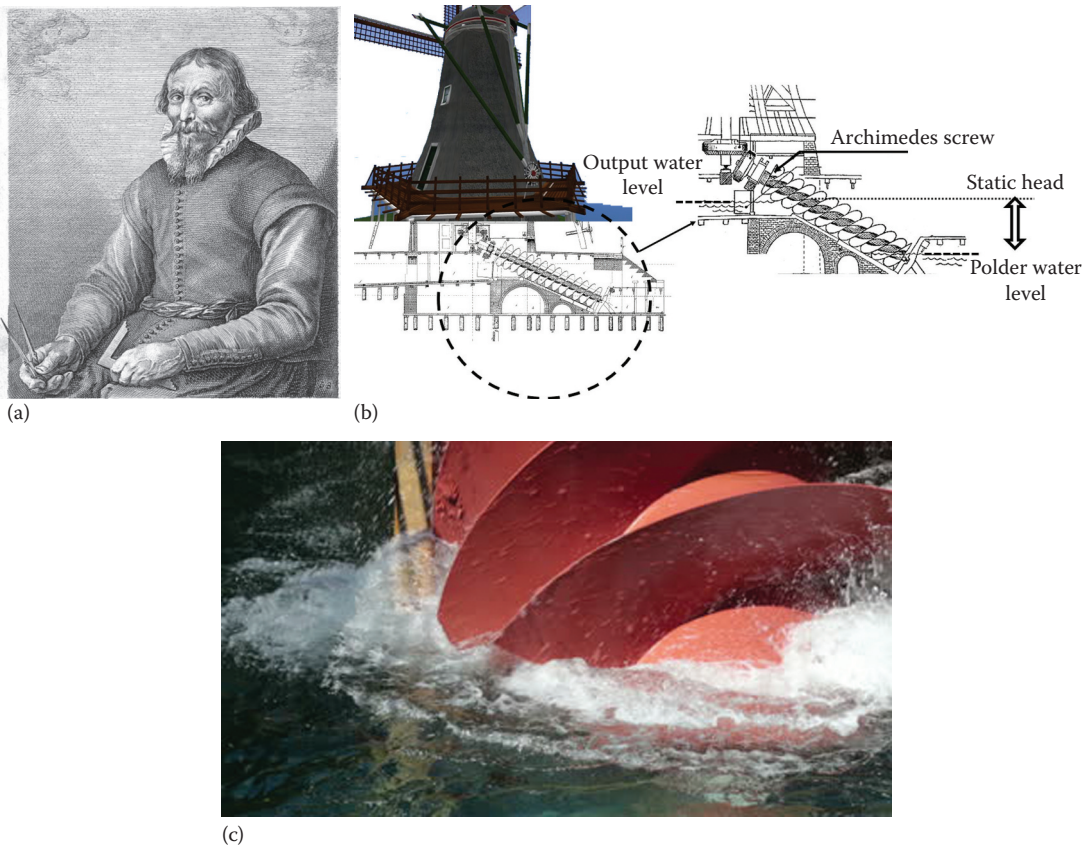


Figure S.103 (a) Jan Adriaanszoon Leeghwater (1575–1650), (b) static head and wind-mill pump, and (c) worm-wheel pump.

Stefan, Joseph (1835–1893)

[general] Physicist and mathematician from Austria (Slovenia). Joseph Stefan is known for his experimental contributions to radiation PHYSICS, in particular the Stefan–Boltzmann equation, with theoretical support from LUDWIG EDUARD BOLTZMANN (1844–1906) (see [Figure S.104](#)).



Figure S.104 Joseph Stefan (1835–1893).

Stefan–Boltzmann law

[atomic, nuclear] ENERGY OF PHOTON spectral emission power profile. The energy power profile is derived from integration of the Planck radiation law. Josef Stefan derived in 1879 that the radiance emitted from a blackbody is proportional to the fourth power of the ABSOLUTE TEMPERATURE of the blackbody as $\Phi^b(T) = \sigma_{\text{Stefan}} T^4$, $\sigma_{\text{Stefan}} = 5.67 \times 10^{-8} \text{ W/m}^2 \text{K}^4$ Stefan-Boltzmann coefficient/constant; with theoretical proof provided by LUDWIG EDUARD BOLTZMANN (1844–1906) in 1884; FLUX, units Watt per meter squared. The fully developed empirical and theoretical formula of the energy emission from a blackbody comes to $\Phi^b(T) = (2\pi^5 k_b^4 / 15b^3 c^2) T^4$, where $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{kg/s}^2 \text{K}$ the Boltzmann coefficient, $b = 6.62606957 \times 10^{-34} \text{ m}^2 \text{kg/s}$ the PLANCK'S CONSTANT, and $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of LIGHT. Alternatively the photon emission can be written as $\Phi_p^b(T) = \sigma'_{\text{Stefan}} T^3$, where σ'_{Stefan} represents the empirical Stefan-Boltzmann coefficient/constant for photon emission. The Radiance (L) of a body incident on an area A , under ANGLE of incidence θ , within solid angle Ω is linked to the Stefan-Boltzmann emission flux $\Phi^b(T)$ through: $L = \partial^2 \Phi^b(T) / \partial \Omega \partial \cos \theta$.

S

Stereo

[acoustics, general, optics] Primarily the three-dimensionally specified PERCEPTION of sound. Sometimes also used to describe depth perception by the combinatory effects from two eyes. The stereophonic HEARING is the result of the phase discrimination from the two ears with respect to the angular placement of the SOUND sources. As the EAR performs a spatially motivated FOURIER TRANSFORM of the acoustic WAVE based on the local sensitivity of the cochlea, the phase-discrimination will be a function of frequency. Human hearing as a frequency sensation has the ability to distinguish sounds that are less than 5 ms apart in time with respect to defining the individual acoustic events, whereas the wave RESOLUTION is better than 150 μs . Although in general the DEPOLARIZATION rate for the ORGAN OF CORTI in the BASILAR MEMBRANE of the cochlea of the ear is directly proportional to the stimulus frequency, the audio nerve cannot provide depolarization rates of 20 kHz, the upper limit of hearing. Three types of nerves can be identified for the SIGNAL transmission to the brain, one with frequency range around 700 Hz, one with frequency range around 1.3 kHz and one with frequency range around 10 kHz, with respective decreasing bandwidth for the higher transmission rates. The high response rate is tied into the frequency section for the high frequency detection close to the entry point at the oval window. This fact will be one of the limiting factors for phase

discrimination apart from the mechanical elastic dampening of the basilar membrane. The frequency hearing is in fact spatially defined by location on the basilar membrane. The locations on the basilar membrane are sensitive to one frequency only, with high frequency sensitivity at the cochlear base (oval window; modulated by the stapes from the INNER EAR) and low frequency sensation at the cochlear apex. Low frequencies (base) is not very useful in stereophonic detection due to the long wavelengths involved that are several times the dimensions of the human head. An acoustic wave in AIR of 20 Hz has a wavelength of 17 m, while 2000 Hz corresponds to 0.1717 m, based on the elastic modulus of air of $Y_{\text{elast}} = 1.41 \times 10^5 \text{ N/m}^2$ and density $\rho = 1.29 \text{ kg/m}^3$, or respectively a speed of sound $v_s = \sqrt{(Y_{\text{elast}}/\rho)} = 331 \text{ m/s}$ as experimentally verified. The use of two ears for humans can distinguish the PHASE of a single frequency of better than 90° , which will provide millimeter wave discrimination at the higher frequencies (note that the upper limit is approximately 10 kHz, at which the approximately wavelength is 3 cm with quarter wavelength resolution: 7.5 mm in the spatial domain; $<150 \mu\text{s}$ in the time domain) with associated spatial resolution of better than 5° in free space; whereas bats have a resolution of better than 1.5° . The auditory signal processing on a central nervous system and cranial level also applies a form of phase-locking for ultimate frequency discrimination and ensuing spatial resolution. All these auditory features provide the means for the human ear to mentally determine the location of the violinist, cellist, the trumpet player and the GUITAR player on the podium, as well as several other instruments. The location of the base drum is generally not specifically known from frequency information, however there is also AMPLITUDE information encoded that will assist in the spatial location determination using the phase locking mechanism-of-action of hearing. Humans can distinguish sound levels as small as 2 dB, specifically at low amplitude (note that 3 dB signifies half the amplitude). Even though stereo is primarily applied to hearing, however in theory stereoscopic VISION refers to the fact that with both eyes humans and other animals (e.g., mammals, birds, amphibians, and reptiles) can perceive depth, while insects with compound eyes have a very different signal processing concepts.

Stern, Otto (1888–1969)

[atomic, nuclear, quantum] German physicist who experimentally verified the QUANTUM THEORY, specifically for ELECTRON SPIN, in 1920, 2 years prior to the release of the official definition of electron spin, in collaboration with WALTHER GERLACH (1889–1979) (see [Figure S.105](#)).



Figure S.105 Otto Stern (1888–1969) in 1928, photographer P. Toschek.

Stern-Gerlach experiment

[atomic, nuclear, quantum] Experimental observation of a split in a beam of neutrally charged particles passing through a MAGNETIC FIELD. This experiment illustrated the inherent magnetic properties of the ATOM, and subsequently for electrons. The atomic MAGNETIC DIPOLE could be the only explanation for the split, based on the quantization of the angular momentum of the magnetic SPIN of the electrons, since the silver atom as used is balanced in electron configuration (BOHR ATOMIC MODEL). Since the beam of silver-atoms was split into two and this could only be attributed to the any single electron, hence the ELECTRON SPIN was baptized as $1/2$. The experiment was executed by OTTO STERN (1888–1969) and WALTHER GERLACH (1889–1979).

Stevin, Simon (1548–1620)

[engineering, general] Scientist and mathematician from the Netherlands. Simon Stevin was active in astronomy, GEOGRAPHY, mathematics, and logics. Stevin also introduced the Dutch word for mathematics: “wiskunde.” Simon Stevin published an all-encompassing review of mathematical approaches for ENGINEERING and PHYSICS in 1608 that were known up to that time from the early Greek philosophers, Arabic mathematicians, to more recent contributions, at least with supporting work from LEONARDO DA VINCI (1452–1519). The work predates the contributions from the range of well-known mathematicians that introduced their work in the mid and late 1600s and from there on: RENÉ DESCARTES (1596–1650), BLAISE PASCAL (1623–1662), GIOVANNI DOMENICO CASSINI (1625–1712), JEAN-BAPTISTE LE ROND D’ALEMBERT (1717–1783), JOHANN HEINRICH LAMBERT (1728–1777), JOSEPH LOUIS LAGRANGE (1737–1813) [comte de Lagrange], PIERRE-SIMON DE LAPLACE (1749–1827), and ADRIEN-MARIE LEGENDRE (1752–1833), in addition to a broad range of experimentalists that also supported their work with pure and applied mathematics. Also predating SIR ISAAC NEWTON (1642–1727) (see [Figure S.106](#)).



Figure S.106 Simon Stevin (1548–1620).

Stimulated emission

[atomic, optics] The encouragement (i.e., enhanced PROBABILITY) provided by a PHOTON that passes an excited electron state to release its ENERGY in the form of a photon. The stimulation process is based on the fact that the incident photon has an energy content ($E = h\nu$, $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK’S CONSTANT, ν the electromagnetic frequency) that is equal to or greater than the difference in energy between the excited state and the GROUND STATE of the electron in the unstable raised energy condition. When the medium of excited atoms/molecules only has one mechanism for EXCITED STATES than the released photon will by definition be identical to the stimulating passing photon. This latter condition provides the foundation for the LASER operational mechanism-of-action (see LASER).

Stirling, Robert (1790–1878)

[mechanics, thermodynamics] Clergyman and scientist from Scotland, Great Britain. Robert Stirling is known for the introduction of the closed-cycle ENGINE, also referred to as a external combustion engine. The closed Stirling process relies on a heat-exchanger for supplying the ENERGY to maintain the MOTION in the PHASE DIAGRAM (P-V diagram; pressure vs. volume), respectively temperature versus entropy diagram (T-S diagram) (see [Figure S.107](#)).



Figure S.107 Robert Stirling (1790–1878).

Stirling cycle

[thermodynamics] Gas compression cycle consisting of two isochoric (i.e., constant volume) step and two isothermal (i.e., constant temperature) segments. The process and ENGINE was patented by ROBERT STIRLING (1790–1878) in 1816. Compare to OTTO CYCLE and CARNOT CYCLE (see [Figure S.108](#)).

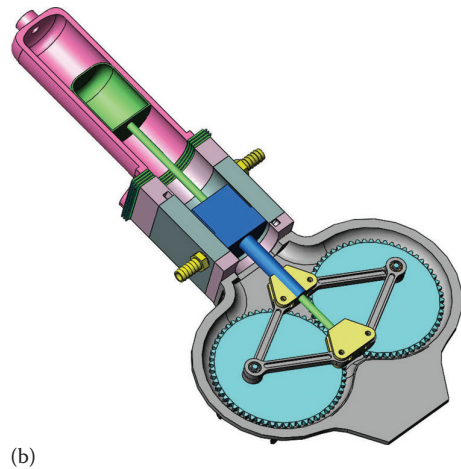
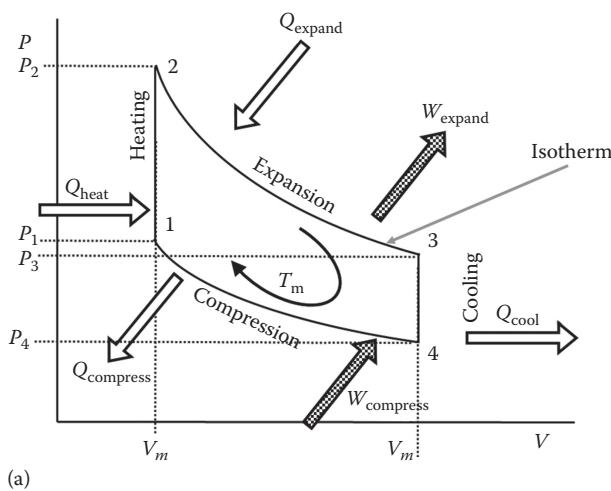


Figure S.108 (a) Stirling cycle. (b) Rhombic drive Beta type Stirling engine design. (Courtesy of Tobias.)

Stochastic process

[biomedical, computational, quantum] Events that are nondeterministic and are defined through a statistical PROBABILITY distribution. One specific example is BROWNIAN MOTION. Another being “RANDOM WALK” in optical simulation as illustrated by the use of a “Monte Carlo” simulation.

Stoichiometric coefficient, $(v_i^{(j)})$

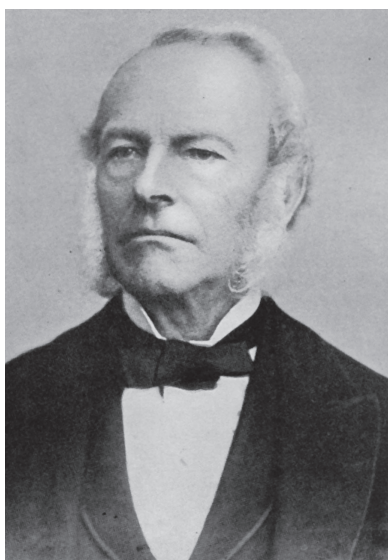
[chemical, thermodynamics] In chemistry the Stoichiometric Coefficients are the constants in the reaction in relative proportions to form a product: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$. In THERMODYNAMICS the Stoichiometric Coefficients $(v_i^{(j)})$ indicate the respective number of participating constituents (reactants) and products $[A_j]$, where the products have a negative value and the ingredients have a positive value so that the sum of the reaction balances at zero: $\sum_{i=1}^r v_i^{(j)} A_j(p) = 0$; where “ p ” indicates the PHASE of the component: GAS, liquid, or solid. Also known as Stoichiometric number.

Stoichiometry

[chemical, thermodynamics] Accounting of quantities of reactants and products in relative proportions with respect to chemical reactions. Stoichiometry is based on the law of CONSERVATION OF MASS. The total mass of the sum of all the reactants is equal to the total mass of all the products. This prescribes the relations among quantities of reactants and products in the form of a ratio of positive integers: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$.

Stokes, George Gabriel, Sir (1819–1903)

[atomic, computational, fluid dynamics, general, optics] Irish mathematician and physicist. Pioneer in the mathematical description of FLUID flow, CREEP and optical phenomena such as diffraction. Additional work of Sir Stokes refers to the ENERGY loss in FLUORESCENCE with the associated longer emission wavelength than excitation wavelength. In the field of fluorescence he is best known for the STOKES LINES (see [Figure S.109](#)).



(a)



(b)

Figure S.109 (a) Sir George Gabriel Stokes (1819–1903). (b) Painting by Lowes Cato Dickinson. (Courtesy of Collection: Pembroke College, Cambridge, UK.)

Stokes drift

[fluid dynamics] In shallow water there is deviation from linear behavior in flow conditions. Liquid packages will be considered to circulate in closed loops during WAVE MOTION, however the particles moving with the wave motion and with the flow in the exterior of the WAVE have a higher velocity than LIQUID packages in the submerged part of the FLUID, which is moving in the opposite direction as the surface package flow and against the fluid-flow direction breaking the presumed circular package pattern. A net fluid-package motion can be defined that accounts for this nonlinearity in a second order phenomena. This phenomena also contributes to the description of the occurrence of undertow. The second-order liquid flow average velocity (v_{Stokes}) is described by the Stokes-drift as $v_{\text{Stokes}} = C_{\text{Stokes}} (a_w k)^2 e^{-2kh_a}$, where the average depth of the liquid level is h_a , the wavenumber is $k = 2\pi/\lambda$, C_{Stokes} is a constant and a_w is AMPLITUDE of the wave. When the wave amplitude is in the range of the depth of the water a phenomenon called wave-shoaling occurs. During wave shoaling the water waves are subject to refraction, generating so called longshore currents. This nearshore CIRCULATION can cause hazardous swimming conditions with longshore current velocities reaching 2.5 m/s, and rip current velocities on the order of 1.5 m/s. This DISPERSION is associated with the phase and group velocities and is linked to the high waves followed by low waves, generating a periodic fluctuation in water level, referred to as “surf beat,” a pulsation effect. These rip currents can have a history tracing outward into sea for over 1.5 km (see Figure S.110).



(a)



(b)

Figure S.110 (a,b) Ocean shoreline Stokes drift.

Stokes' Law

[atomic, computational, fluid dynamics, general] Description of the characteristic sedimentation speed (v) for a particle in suspension in LIQUID or GAS. Introduced by SIR G. STOKES (1819–1903). The process also applies to two liquids that do not mix (e.g., water and OIL), or the dissociation of gas/vapor-bubbles from a liquid. This applies for instance to centrifugation and can be formulated as $v = (2(\rho_p - \rho_\ell)gr^2)/9\eta$, where ρ_p

is the particulate (solved constituent) density, ρ_ℓ the density of the liquid, η is the VISCOSITY, r the PARTICLE radius, and g the GRAVITATIONAL ACCELERATION. For the removal of BUBBLES the approach needs to take into consideration the BUOYANCY acting against DRAG force.

Strain (ϵ_s)

[general] Deformation (ΔL) per unit length (L), used as linear strain: $\epsilon_{s,\ell} = \epsilon_{\text{strain},\ell} = \Delta L/L_0$, shear strain; the angular deformation $\epsilon_{\text{strain},\alpha} = \Delta\alpha/\alpha_0$, and volumetric strain; the change in volume per unit volume: $\epsilon_{\text{strain},V} = \Delta V/V_0$. Elastic strain will allow the medium to return to its original shape and size. Inelastic strain usually requires exceeding a threshold strain, at which point the deformation becomes permanent, or at least no full recovery is achieved upon unloading the applied stress. Under certain conditions the atomic configuration can be modified to become more resistant to elastic deformation, strain hardening. Strain hardening can be achieved by material treatment process, most well-known is a temperature treatment. Hardening can be induced by deformation at a temperature below the recrystallization temperature (cold-forming) followed by low-temperature heating, or by rapid cooling of low-carbon steel, both used for instance in the treatment of sword-blades by a blacksmith. The high temperature heating followed by rapid cooling is referred to as quenching and creates a hard but brittle structure (martensite). The cold-forming treatment creates a durable METAL (*also see* HOOKE'S LAW) (see [Figure S.111](#)).

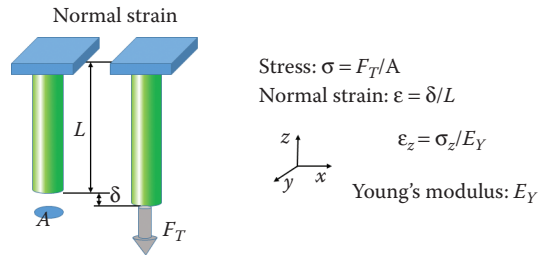


Figure S.111 The strain principle.

Strain gauges

[general] Sensor strip that sends off an electrical SIGNAL on deformation. Strain gauges are made from piezoelectric ceramics materials as well as polyelectrolytes, metallic [microelectromechanical systems (MEMS)] and carbon-nanotube—POLYMER composites (e.g., PVA: polyvinyl alcohol; conductive PDMS: polydimethylsiloxane, with carbon backing), and gold nanoparticle composites and a range of electrically conductive materials. Other RESISTANCE strain gauges use a conductive material embedded in a flexible strip or band, for instance in biomedical applications the “mercury-in-rubber” gauge is popular due to its versatile applications for fitting around biological appendages (toes, fingers, ankle). Most of these applications rely on resistive changes for determination of degree of strain. A different variety of strain gauge uses capacitive coupling for two layers of thin material. Other mechanisms-of-action include fiberoptic LIGHT guides. The FIBER-OPTIC changes the local reflectivity on the core-cladding transition, changing the interferometric standing wave conditions. This type of fiber is extremely narrow and can be imbedded with little or no influence on the structural integrity. The fiber-optic strain gauge is used in monitoring the structural integrity of METAL or concrete bridges and buildings, as in polymer/fiberglass structures, such as race boats and racecars for safety information. The primary difference for the fiber-optic strain gauge is the location-specific information that can be imbedded in the optical signal structure for a single fiberoptic strand. The location-specific information is derived from multiplexing. Multiplexing is a technique that is also used in fiber-optic communications, carrying multiple signals simultaneously on a single fiber leading to

numerous individual terminal stations on a station-specific basis. The strain gauge was invented by Arthur Claude Ruge (1905–2000) and Edward E. Simmons Jr. (1911–2004) in 1938. Strain gauges have a very high duty cycle and can measure strain fluctuation in the order of several hundred kHz, also dependent on the size and thickness of the sensor material. There is usually a trade-off between the range of applied force that can be tolerated and the frequency response. A flexible strain gauge can be wrapped around a flexible tube to measure relative local pressure changes based on the radial EXPANSION. In order to enhance accuracy and avoid environmental influences two strain gauges can be matched in a WHEATSTONE BRIDGE type configuration, adjusting for optimal RESOLUTION on one strain gauge while the other is not subjected to change, other than environmental conditions, specifically temperature effects (see [Figure S.112](#)).

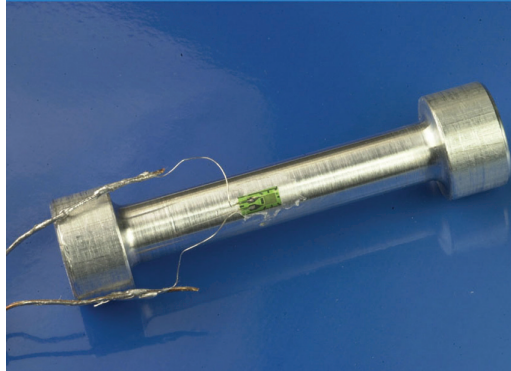


Figure S.112 Strain gauge. (Courtesy of www.doitpoms.ac.uk/; University of Cambridge, Cambridge, UK.)

Stratosphere

[energy, general, geophysics, thermodynamics] Atmospheric shell around the EARTH, the second layer of ATMOSPHERE on top of the TROPOSPHERE and below the MESOSPHERE. The stratosphere spans from an altitude at approximately 10–50 km, while the stratosphere above the poles starts at an altitude of 8 km and above the equator as high as 18 km. The stratosphere forms a protective layer from ULTRAVIOLET RADIATION due to the absorption of UVB and UVC in the formation of atomic (O) and diatomic oxygen (O₂) from ozone (O₃) in the outer edge of the stratosphere (stratopause), which are recombining in the mid-stratosphere to form ozone again. The recombination process releases ENERGY, which makes the middle stratosphere warmer than the lower stratosphere, which contributes to its stability. The outer edge of the stratosphere has a temperature just at 270 K $\cong$ -3°C , just below the FREEZING point of water. Commercial AIR traffic takes place in the lower stratosphere, 9–12 km altitude. Due to the lower density than the troposphere the air-drag for the planes is reduced, resulting in more fuel-efficient flight. In comparison, the Concorde would fly at 18 km altitude with velocity of Mach 2 (twice the speed of SOUND), and the Lockheed SR-71 blackbird spy plane would cruise at 26 km altitude at Mach 3. The stratosphere has various flow mechanisms. Horizontal MIXING is more prevalent than vertical mixing. One specific flow mechanism resulting from thermal and chemical gradients under the influence of GRAVITATIONAL WAVES is quasi-biennial OSCILLATION. Quasi-biennial oscillation is characteristic for the stratosphere and was discovered in the 1950s by meteorologists from Great Britain and has shown great influence on large weather patterns, such as the monsoon. In the quasi-biennial oscillation the quasiperiodic oscillation period in 28–29 months, yielding fluctuations in wind passage in the equatorial zonal alternating between eastward and westward. The alternating wind regimes originate in the upper level of the lower stratosphere and migrate downwards at about 1 km per month, where the propagation is subject to a damped oscillation, dissipating at the tropical tropopause. The downward propagation on the westward flow is usually more irregular than that of the westward flow. Hence the

AMPLITUDE of the easterly migration is about twice as large as that with respect to the westerly PHASE. The quasi-biennial oscillation has been confirmed by weather balloon observations (see Figure S.113).

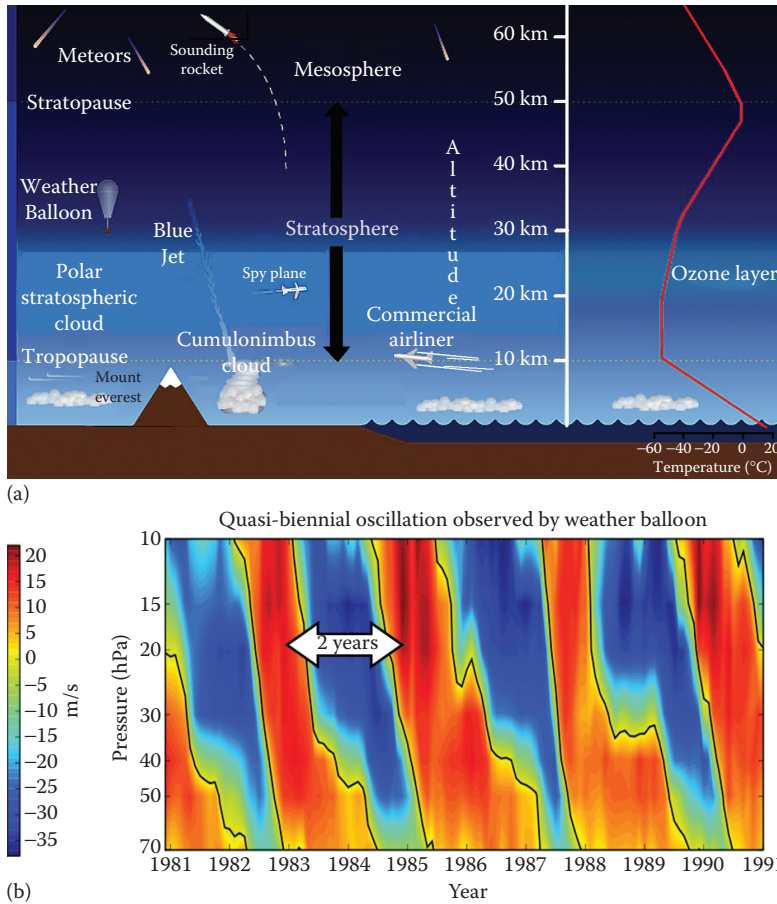


Figure S.113 (a) Stratosphere. (Courtesy of Randy Russell, University Corporation for Atmospheric Research [UCAR], Copyright 2009, <http://scied.ucar.edu/imagecontent/stratosphere-diagram>.) and (b) Quasi-biennial oscillations in the pressure outline of the stratosphere. (Courtesy of The Freie Universität Berlin [Germany; Markus Kunze] supplies a QBO data set that comprises raw “insonde” observations from Canton Island, Gan, and Singapore based on the work of Naujokat, B. and Naujokat, B., 1986. An update of the observed quasi-biennial oscillation of the stratospheric winds over the tropics. *J. Atmos. Sci.*, 43, 1873–1877.)

Stream function

[fluid dynamics] A two-dimensional flow will originate in any arbitrary (but fixed) point (point A) and flow to a second point in the two-dimensional plane that is variable (point B) in its location. The FLUX between these two point can be represented by any line connecting point A and B, without leaving the boundary conditions (remaining with a confined area), without losing or gaining mass, represented by a stream function Ψ . The flow will adhere to the Navier-Stokes equation. For any point in the coordinate system (x, y) {“x” the abscissa for the coordinate of point A} there are velocities associated $u = -(1/\rho)(\partial\Psi/\partial y)$ and $v = +(1/\rho)(\partial\Psi/\partial x)$ (fluid density: ρ) that provide stream-lines that form an ANGLE (θ) with the normal to the curve (s) connecting A and B at any location δs , represented as $\theta' = \cos\theta$; $\theta'' = \sin\theta$. The flux is represented by the steam function as $\Psi = \int_A^B (\theta' u + \theta'' v) ds$. For IRROTATIONAL FLOW the following condition applies: $(\partial^2\Psi/\partial x^2) + (\partial^2\Psi/\partial y^2) = 0$. This is the Lagrange stream-function. In three-dimensional flow (coordinate system $[r, \phi, z]$) the flow function for incompressible, rotation free flow (axial symmetry) will adhere to $u_r = -(1/\rho)(\partial\Psi/\partial z)$, $v_z = +(1/\rho)(\partial\Psi/\partial r)$. From the stream function the streamlines can be

derived through: $\nabla \Psi \cdot \vec{n} = 0$. The streamlines provide a graphical interpretation of the flow by means of the density of the lines, and the cross-sectional area traversed. In practicality, the streamline represents the track followed by an individual PARTICLE, on average for a large number of particles (i.e., molecules).

Stress (σ_s)

[fluid dynamics, general, mechanics] Force (F) parallel to a cross-sectional area A resulting in the potential for deformation: $\sigma_s = F/A$. TENSILE STRESS describes the linear deformation, stretching or compressing, with forces acting along the line of action. Bulk stress is equivalent to pressure, imposing a change in volume. Shear stress represents two equal but opposing forces acting in parallel planes, providing angular deformation (*also see* SHEAR-STRESS) (see [Figure S.114](#)).

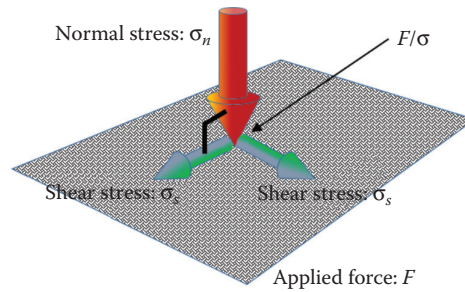


Figure S.114 The concept of Stress illustrated by vector diagram.

Stress birefringence

[general, optics] Stress applied to an optically transparent object will result in stress related changes in index-of-refraction, generating a focusing and DISPERSION, resulting in a COLOR pattern in response to the transmission of WHITE LIGHT. STRESS BIREFRINGENCE can be used for noninvasive quality control purposes. The stress may result from the structure of the device or as a result of an externally applied force (see [Figure S.115](#)).



Figure S.115 Stress birefringence. (Courtesy of Andrew Davidhazy.)

Strong nuclear force

[computational, energy, general, nuclear, quantum, relativistic, solid-state, thermodynamics] Short range strong force maintained by the elementary PARTICLE gluon. The range is approximately 1×10^{-15} m. The strong nuclear force is the strongest of the FOUR BASIC FORCES. The strong nuclear force acts on a property defined as “COLOR,” which has three states: r, g, b (also referenced as: red, green and blue). This in comparison with the electromagnetic forces that act on charges (positive and negative) and the gravitational force which acts on mass (see [Figure S.116](#)).

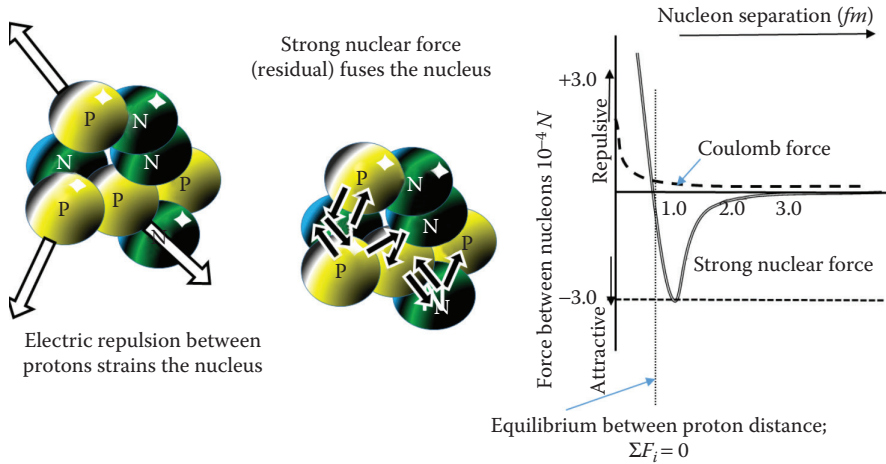


Figure S.116 Strong nuclear force interaction. The two opposing forces in a nucleus are (1) the electrical Coulomb repulsion between the positively charged protons and, respectively, (2) the residual strong nuclear force. The strong nuclear force provides the attraction between the protons and neutrons, specifically if the numbers of neutrons and respectively protons are not too much different in quantities, and hence overpowers the repulsive electrical forces.

Strouhal number ($Sr = vL / v_v$)

[biomedical, fluid dynamics] Dimensionless number in momentum transfer relating the inverse of the VORTEX SPACING, specifically for Von Kármán vortices and in UNSTEADY FLOW. The Strouhal number provides a classification of the ratio of forces resulting from acceleration under unsteady flow to the inertial forces from changing velocity (both magnitude and direction) in the turbulent flow pattern as a function of location. In the definition the following parameters are used: v_v : frequency of VORTEX SHEDDING (VORTEX SHEDDING FREQUENCY), L characteristic length and v the velocity of flow. The Strouhal number classifies and describes the characteristic phenomena of oscillating flow, such as pulsatile BLOOD flow. For most fluids both the flow frequency and velocity profile depend on the viscosity, more specifically the FLUID characteristics (e.g., pseudoplast, Newtonian, or dilatant fluid). A small Strouhal number ($Sr \ll 1$) correlates with a QUASI-STEADY STATE flow pattern, while high Strouhal numbers reference vortex shedding, the separation of a vortex flow pattern (at approximately $Sr = 0.2$).

Student's t-test

[biomedical, computational, solid-state] Statistical PROBABILITY distribution. The name “Student” was the pseudonym for W.S. Gosset, a quality control engineer with the Guinness beer brewery in Dublin, Ireland to hide his identity from the employers that were afraid of information about the processes leaking out. The publication in 1908 set the stage for all modern statistical analysis based on the distribution of the deviation from the mean value ($\bar{X}$) of a series of observations (n) described as $P_{\text{population}} = (\bar{X} - \mu_{\text{stat}}) / (s_{\text{variance}} / \sqrt{n})$, where $\mu_{\text{stat}} = \sum_{i=1}^n x_i P_{\text{stat}}(x_i)$ provides the weighed mean based on individual value (x_i) with respective probability of occurring ($P_{\text{stat}}(x_i)$) and $s_{\text{variance}}^2 = [1/(n-1)] \sum_{i=1}^n (x_i - \bar{x})^2$ is the standard deviation (also referred to as σ_s) of the variable x , with mean value $\bar{x}$. The t-test depends on whether the population distribution is a “NORMAL DISTRIBUTION.” The

distribution of the population of values ($P_{\text{population}}$) is evenly distributed around zero, or the mean value (depending on notation), with a “Gaussian shaped” slope that is a function of the number of DEGREES OF FREEDOM defining the variable x , described in the t -distribution as t_m , with m the number of degrees of freedom. The larger the number of degrees of freedom the closer the t -distribution approaches a Z -distribution.

Sturgeon, William (1783–1850)

[general] Scientist and inventor from Great Britain who developed the electromotor in 1832, based on the work of the early (static ELECTRICITY) work by the Scottish monk Andrew Gordon (1712–1751) in the 1740s. additional contributions came from the theoretical work by ANDRÉ-MARIE AMPÈRE (1775–1836) in 1820 and MICHAEL FARADAY (1791–1867) in 1821 (see [Figure S.117](#)).



Figure S.117 William Sturgeon (1783–1850).

Sturm, Jacques Charles François (1803–1855)

[computational] Mathematician from France. Jacques Sturm dedicated his work to solving complex integral equations and polynomials, specifically defining the roots of higher order polynomials (see [Figure S.118](#)).



Figure S.118 Jacques Charles François Sturm (1803–1855).

Sturm–Liouville technique

[computational] Standard procedure to solve certain types of differential equations by developing into eigenfunctions, with solutions containing eigenvalues. The Sturm–Liouville technique is a collaborative effort between JACQUES CHARLES FRANÇOIS STURM (1803–1855) and JOSEPH LIOUVILLE (1809–1882). The differential equation is expressed as an interaction between a set of functions (continuous functions: $f(x)$; $g(x)$; $b(x)$) with EIGENFUNCTION “SOLUTION” $y(x)$ outlined as $-(d/dx)[f(x)[\partial y(x)/\partial x]] + g(x)y(x) = c;b(x)y(x)$, with the boundary conditions specified through the

constant c_i , the eigenvalues ($c_1 < c_2 < c_3 < \dots < \infty$). The constraints on the eigenfunction is that it is continuously differentiable in the domain of the function. The function $b(x)$ defines the weight or NORMALIZATION.

Subatomic particles

[general] Particles that constitute the atomic model described by Bohr as well as the ELEMENTARY PARTICLES that form the atomic particles. Whereas atoms for the building blocks for MACROSCOPIC entities, ranging from LATTICE structures to molecules to objects. The objects form the components and dressing for planets and the atoms and molecules for the foundation of the nuclear reactions maintaining stars. In the opposite direction the ATOM is constructed from constituents that can be dissected in smaller and smaller entities. Atomic particles are electrons in the shells; respectively neutrons and protons in the NUCLEUS (nuclides). The atomic components are constructed from elementary PARTICLE we categorize as fermions and bosons. Fermions is a subgroup of what is known as elementary particles with odd spin ($1/2, 3/2, 5/2, \dots$), whereas BOSON have integer spin ($0, 1, 2, \dots$). These groups are further split in quarks and leptons. These subgroups are further subdivided in generations. The first generation of elementary particles are the ELECTRON (e^-), UP-QUARK (u), down quark (d) and electron-type NEUTRINO (ν_e). The second generation consists of MUON (μ), strange quark (s), CHARM quark (c) and muon-type neutrino (ν_μ). The third generation has top quark (t ; also known as truth) and bottom quark (b) next to the tau particle (τ) and tau-type neutrino (ν_τ). In addition all these first through third generation particles also have anti-particles, generally designated by a bar across the base symbol for the first order particle ($\bar{u}, \bar{d}, \bar{\nu}_e$, etc.), except for the positron; the anti-particle of the electron: e^+ . Hadrons are a family of particles that are constructed from quarks and antiquarks in a range of combinatory assemblies, presumably the PROTON the only stable HADRON in existence; accounting for their possible neutron DECAY (however in general the NEUTRON is also stable as NUCLIDE. Hadrons consist of subfamilies: baryons and mesons. For every hadron species there is an antiparticle. Baryons are MATTER particles, and mesons are designated as force particles. All baryons consist of three quarks, most well-known are the neutron and the proton in this class. Additional baryons are “Lambda-Zero” (Λ^0); “Omega Minus” (Ω^-); as well as permutations of Δ ; Ξ ; and Σ . Mesons are constructed of quark—anti-quark pairs only. So far no further delineation has been found for even smaller units that form the fermions and bosons, but this is currently mainly due to the equipment limitations required for verification. Some of the “elementary” particles were only theoretical assumptions dating back half a century and have only recently been provided with experimental support. (Note: The HIGGS BOSON [see QUARK, ELECTRON, and PROTON]) (see Figure S.119).

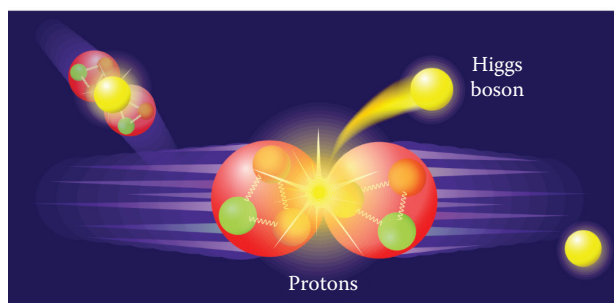
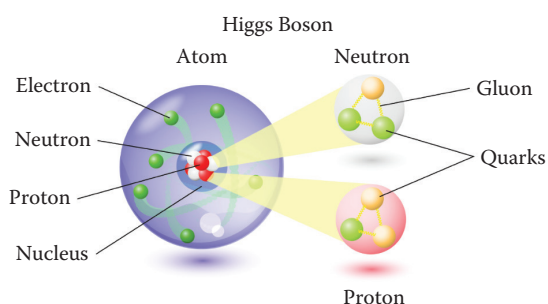


Figure S.119 Subatomic particle outline.

Sublimation

[general, thermodynamics] PHASE TRANSITION from solid to GAS. The terminology VAPOR is frequently used to identify a gas in equilibrium with its solid or LIQUID phase. The atomic or molecular ENERGY exceeds the BINDING ENERGY constraining them to their solid phase. Sublimation reduces the fraction of high-energy components in the solid, hence bringing the average kinetic energy down, thus reducing the overall temperature of the system, that is, cooling (see Figure S.120).



Figure S.120 Sublimation.

Subshell

[atomic, solid-state, thermodynamics] The BOHR ATOMIC MODEL is constructed in primary and secondary SHELLS. The primary shells are named in outgoing order as follows: K, L, M, N, O, P, and Q, corresponding with the PRINCIPAL QUANTUM NUMBER n , which is a positive integer and starts at $n = 1$ associated with the K-shell. The subshells are named: s, p, d, f, and g. The spins of the respective electrons is defined by HUNDS' RULE (sometimes also called HUND'S LAW). The s-subshell can hold two electrons, with respective opposite SPIN. The s-subshell has orbital quantum number (second quantum number, the first or principal quantum number n represents the) $\ell = 0$ and is present in every shell, with incremental numerator number: 1s for K-shell, 2s for L-shell, and so on. In the L-shell there are two subshells 2s and 2p, where the p-subshell is present in every shell outward from the second ordinal. The p-subshell has orbital or azimuthal quantum number, $\ell = 1$ and has the potential for containing six electrons (respectively two each for the third quantum number (i.e., MAGNETIC QUANTUM NUMBER) which defines the angular momentum, which ranges from $m_\ell = [-\ell, -\ell + 1, \dots, 0, \dots, \ell - 1, \ell]$, or $2\ell + 1$ possible states, yielding: $m_\ell = -1$, $m_\ell = 0$, $m_\ell = 1$). In the Bohr atomic model the f-subshell may contain a total of 7 pairs of electrons, 14 total and the f-subshell appears in the N-shell for the first time. One can illustrate the configuration of the shell/subshell arrangement with the appropriate ENERGY nomenclatures in tabular format.

Sun

[astrophysics, atomic, general, geophysics, nuclear, optics, quantum] STAR central to our own SOLAR SYSTEM. Hydrogen NUCLEAR FUSION reactor producing a broad spectrum of particulate and electromagnetic RADIATION, and emitting on average $63 \times 10^6 \text{ W/m}^2$. Of which only approximately $1.2 \times 10^3 \text{ W/m}^2$ reaches EARTH on perpendicular incidence. Note that the global radiance fluctuations are a function of the location on Earth (ANGLE of incidence), time of day and the seasonal DISTANCE to the Sun (r^{-2} dependance). The average distance from the Sun to Earth is $1.496 \times 10^{11} \text{ m}$. The average surface temperature of the Sun is 5778 K. The mass of the Sun is in approximation $M_\odot = 1.989 \times 10^{30} \text{ kg}$, containing greater than 99.8% of the total mass for our solar system of Sun and planets (JUPITER containing a significant total mass as second largest object), with solar radius $R_\odot = 6.958 \times 10^8 \text{ m}$. The Sun and associated solar system including Earth are close to the outer edge of the MILKY WAY galaxy and we all orbit the center of the Milky Way galaxy.

Sunlight takes on average 8.3 min to reach Earth, traveling at the speed of LIGHT. The FUSION process in the PLASMA of the Sun proceeds as follows. The first to steps are the fusion of hydrogen; proton fusion (${}^1_1\text{H}$) with the release of a positron (e^+) and electron NEUTRINO (ν_e): ${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^2_1\text{H} + e^+ + \nu_e$, followed by step two ${}^1_1\text{H} + {}^2_1\text{H} \rightarrow {}^3_2\text{He} + \gamma$, emitting high ENERGY gamma radiation (γ) and deuterium (${}^2_1\text{H}$). There are a number of possibilities for the third stage fusion process, the dominate process: ${}^3_2\text{He} + {}^3_2\text{He} \rightarrow {}^4_2\text{He} + {}^1_1\text{H} + {}^1_1\text{H}$, forming helium. All three process produce approximately $27\text{ MeV} = 4.326 \times 10^{-12}\text{ J}$. The outlines of this process was first described by the German nuclear physicist HANS ALBRECHT BETHE (1906–2005) in 1939, for which he was awarded the Nobel Prize in Physics in 1967. The work of Hans Bethe was based on the initial conceptual description by the British physicist Sir ARTHUR STANLEY EDDINGTON (1882–1944) in 1920. The Sun holds the planets in the solar system, with respective mass m , in orbit by means of gravitational attraction as a function of distance (r) as defined by SIR ISAAC NEWTON's (1642–1727) LAW OF UNIVERSAL GRAVITATION: $F = G(mM_{\odot}/r^2)$, with $G = 6.67 \times 10^{-11}\text{ Nm}^2/\text{kg}^2$ the gravitational constant. The Sun frequently ejects plasma jets known as solar flares, which are accompanied by intense RADIO frequency emissions that influence the wireless communications on Earth (see [Figure S.121](#)).

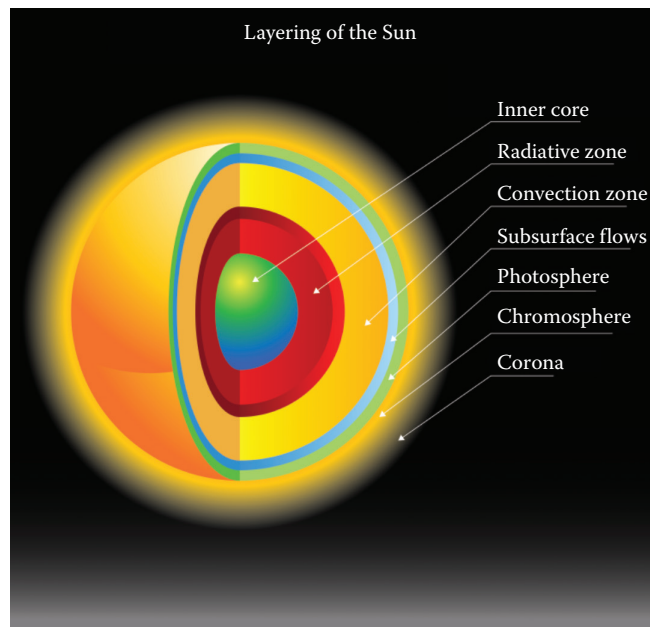


Figure S.121 Sun.

Sun spot

[geophysics, optics] Disturbances in the Sun's convection currents. Sun spots have an apparent 11 year cycle, first observed by GALILEO GALILEI (1564–1642) in 1610. Sun spots are associated with a MAGNETIC FIELD in the order of 1kG (compared to BAR MAGNET $B = 100\text{ G}$) (see [Figure S.122](#)).

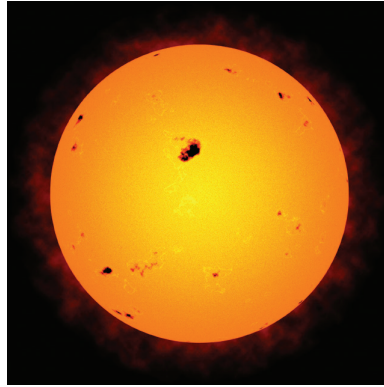


Figure S.122 Sun spots.

Sundog

[geophysics, optics] Atmospheric phenomena that form “mirror” images of the SUN on either side of the Sun in the sky, also referred to as parhelia, frequently coinciding with a halo. The mock suns are the result of atmospheric diffraction due to pressure layers and thermal gradients. The primary aspect of sundogs is in the refraction from ice crystals. In case the Sundogs are formed in pairs they will be at approximately 22° angle from the Sun from the point of the observer (*also see* RAINBOW) (see Figure S.123).



Figure S.123 Sundog.

Superconducting quantum interference device (SQUID)

[general] Superconductive MAGNETIC FIELD sensing device. SQUIDS are used to measure minute magnetic fields, such as produced by the brain, with RESOLUTION and sensitivity down to 10^{-18} T. In comparison, the magnetic field at the surface of an atomic NUCLEUS: 10^{12} T; hair dryer in close proximity 10^{-3} T; small BAR MAGNET near the poles 10^{-2} T; and the geomagnetic field at the earth's surface 10^{-12} T. Squids are miniature superconductive current loop devices developed by the team at the Ford Research Laboratories (part of the Ford Motor Company; Dearborn, MI, USA) consisting of Robert C. Jaklevic (mid-twentieth century–), John J. Lambe (mid-twentieth century–), James Mercereau (mid-twentieth century–), and Arnold Silver (mid-twentieth century–) in 1964. The squid mechanism-of-action is based on the Josephson Effect defined

by the theoretical physicist from the United Kingdom (Wales), BRIAN DAVID JOSEPHSON (1940–) in 1962. The sensitivity is based on the measured current which is a function of the magnetic FLUX passing through the SQUID loop with diameter d and under applied magnetic field strength B , under constraints: $I_c^2 = (I_{c1} - I_{c2})^2 + 4I_{c1}I_{c2} \cos^2(\pi d^2 B / (b/2e))$, where the current is split in the half circumferential proportions I_{c1} , respectively I_{c2} , where $b = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT (see Figure S.124).

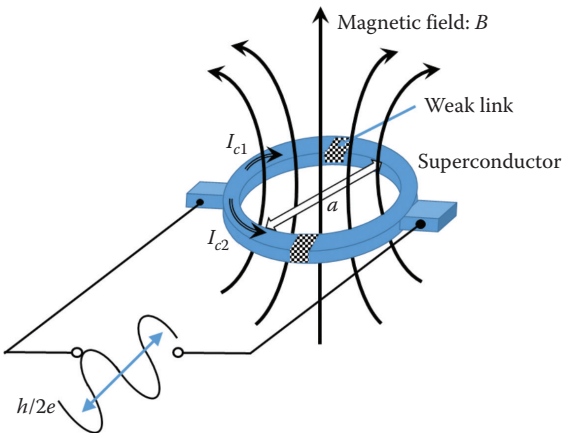


Figure S.124 SQUID design.

Superconductivity

[atomic, energy, solid-state] The fact that materials lose all electrical BARRIERS and have impedance of zero at cryogenic temperatures. The work of KAMERLINGH ONNES (1853–1926) revealed the first signs of superconductivity in 1911.

Supercritical fluid state

[thermodynamics] Specific phenomenological state/phase of a liquid or GAS that is only available above the CRITICAL POINT, explained best in the P–T DIAGRAM (pressure vs. temperature). For water the critical point is defined by $P = 218.3 \text{ atm}$, $T = 374.15^\circ\text{C}$, at this point the FLUID is a supercritical fluid with density $\rho = 0.315 \text{ g/mL}$. In comparison the respective characteristics of gas, liquid and supercritical state are exemplified in the table in order of MAGNITUDE respectively.

STATE	DENSITY (kg/m³)	DIFFUSIVITY (cm²/s)	VISCOSITY (kg/ms)
Supercritical	200–900	10 ^{−4}	10 ^{−3}
Gas	1	10 ^{−1}	10 ^{−3}
Liquid	1000	10 ^{−4}	10 ^{−1}

The supercritical state is identified by conditions of compressibility, which for a LIQUID would under normal circumstances be not allowed, meanwhile the supercritical fluid has the density of a liquid under standard pressure and temperature. The supercritical fluid does neither behave as a liquid nor as a gas, but has characteristics of both and is a new PHASE or state-of-matter.

Supercritical mass

[general] A threshold mass of ISOTOPE material beyond which the material spontaneously fuses, the fissionable material spontaneously initiates a CHAIN REACTION. The most well-known critical mass is the FUSION of URANIUM (enriched) (^{235}U) to produce an extraordinary amount of ENERGY when two segments of approximately half the critical mass are forcefully joined (by means of an explosion) to result in an increase in volume that its surface area, producing a perceived surplus of emitted neutrons causing the DECAY reaction to escalate, resulting in a thermo-nuclear explosion at 52 kg. Other critical mass data for specific ELEMENTS are $^{233}\text{U} \rightarrow 15 \text{ kg}$; $^{236}\text{Pu} \rightarrow 9.04\text{--}10.07 \text{ kg}$ (range); $^{236}\text{Np} \rightarrow 7 \text{ kg}$; and $^{252}\text{Cf} \rightarrow 2.73 \text{ kg}$.

Superfluid

[atomic, nuclear] Extraordinary PHASE of a medium, not GAS, not LIQUID, not solid, which behaves with viscosity $\eta_{\text{kin}} = 0$. The superfluid has entropy $S = 0$, and all atoms are in the same QUANTUM STATE, with identical momentum. The best known example of a superfluid state is Helium, which becomes a superfluid with decreasing temperature at 2.18 K. Superfluid Helium is the most remarkable heat CONDUCTOR (virtually perfect conduction), while remaining electrically neutral, that is, an INSULATOR.

Superheated steam

[general, thermodynamics] Water VAPOR at temperature above 100°C at 1 atmosphere pressure.

Superheated vapor state

[thermodynamics] Evaporated state of a LIQUID at temperature above the vaporization temperature.

Supernova

[astronomy/astrophysics, energy, general] The classification of the end-stage of a STAR, culminating in an explosion and associated massive emission of NEUTRON, photons, neutrinos and variety of charged particles and electromagnetic RADIATION in massive quantities. On EARTH the NEUTRINO and PHOTON emission from an exploding supernova (SN 1987A) in the Tarantula Nebula (also known as the “star-forming region” 30 Doradus or NGC 2070) in the Southern hemispherical orientation for the general direction of the GALAXY: Large Magellanic Cloud (LMC) in the Dorado constellation; at 168,000 light-years DISTANCE from Earth reached the underground detection stations in Cleveland, Ohio, and Tokyo, Japan, in 1987. The emissions from Supernova 1987A, called for the first observation, are still being observed (see [Figure S.125](#)).

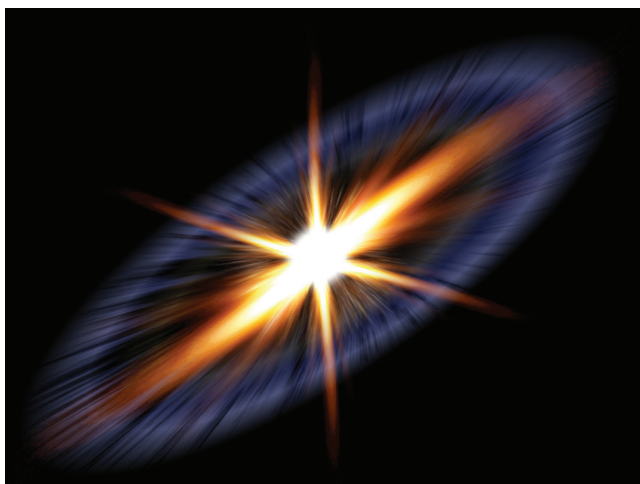


Figure S.125 Supernova.

Supersonic flow

[fluid dynamics] Flow conditions with propagation velocity greater than the speed of SOUND. Supersonic flow results in a dramatic cooling effect, for instance accelerating from rest at room temperature ($25^{\circ}\text{C} = 298\text{ K}$) to Mach 3 will reduce the temperature of the FLUID to $-166^{\circ}\text{C} = 107\text{ K}$. Alternatively an object traveling at Mach 3 will increase its surface temperature due to FRICTION to $530^{\circ}\text{C} \approx 800\text{ K}$. Supersonic flow can be achieved through SHOCK-WAVE formation (see Figure S.126).

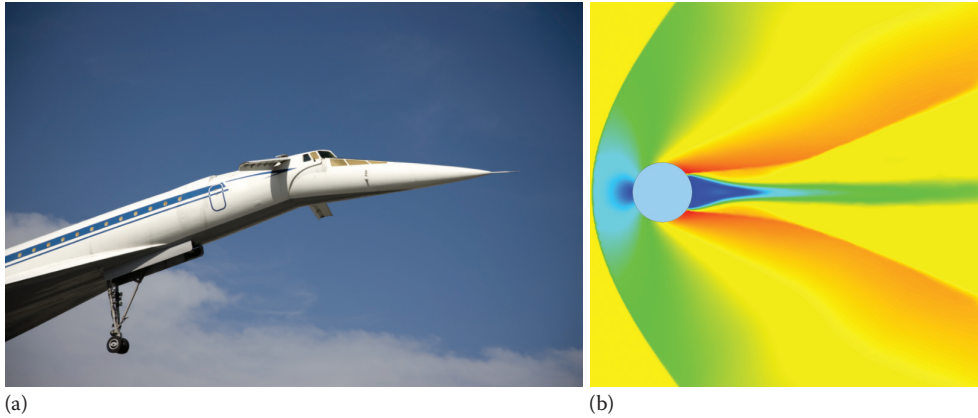


Figure S.126 Supersonic flow. (a) Supersonic aircraft carrier: Concorde (discontinued air transport plane) and (b) computer flow simulation, false-color indication of stream flow velocity.

Surface charge density (σ_{elec})

[general] Charge density on the surface of a CONDUCTOR, evenly spread, defined by the total charge Q on the object, divided by the surface area A : $\sigma_{\text{elec}} = Q/A$. For a nonconductive medium the local charge density will be location specific since there is no free migration of charge. The charge surface density on a curved surface for a conductor will be a function of the radius of curvature, with greater charge density with smaller radius of curvature: $\sigma_{\text{elec},r}/\sigma_{\text{elec},R} = R/r$, where R denotes the large radius of curvature (such as defining the outline for the body of a rounded cone) and r the radius of curvature of the pointy tip (see Figure S.127).

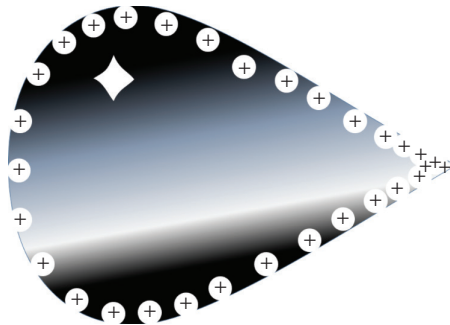


Figure S.127 Surface charge density.

Surface energy

[chemical, fluid dynamics, mechanics, thermodynamics] ENERGY aspect of SURFACE TENSION. The work performed by the force that creates the new surface area. Materials have specific surface energy, for instance the surface energy for the following solids is as follows: KCl has a surface energy of $E'_s = 0.11\text{ J/m}^2$, glass

(BK7) $E'_s = 4.4 \text{ J/m}^2$, mica in VACUUM $E'_s = 5.0 \text{ J/m}^2$, whereas mica in AIR has $E'_s = 0.38 \text{ J/m}^2$, granite has $E'_s = 200 \text{ J/m}^2$. Contamination of the substance will reduce the surface energy. Surface energy is an important factor in crack formation for a solid, but also defines the BUBBLE formation for a VAPOR bubble from a LIQUID or solid.

Surface gravitational wave

[acoustics, fluid dynamics, geophysics, mechanics] WAVE on the surface of a fluid (LIQUID or GAS) that are influenced by gravitational restoring forces. Surface GRAVITATIONAL WAVES are described as Lamb waves on the surface of an AIR mass, or the “surf” on the water of oceans and lakes, in particular breaking on the shore of a landmass (see WAVE or SURFACE WAVE). On a QUANTUM mechanical level the other concept of gravitational wave relates to transverse wave of massless quantum PARTICLE. The concept of quantum-mechanical gravitational waves is directly linked to the ALBERT EINSTEIN’s (1879–1955) principle of general relativity (see Figure S.128).

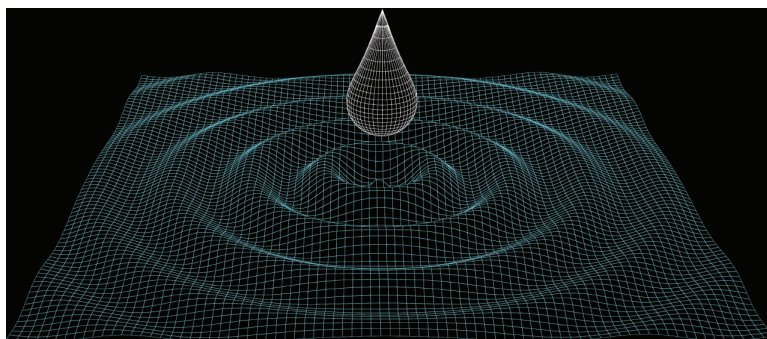


Figure S.128 Surface gravitational wave.

Surface phenomena of Liquids

[chemical, fluid dynamics, mechanics, thermodynamics] A LIQUID is a continuous medium with minimally one surface (spherical symmetry), the surface is exposed to forces and ENERGY constraints. Within a medium similar phenomena can occur in the form of BUBBLE, also only one continuous surface. In a container the walls of the container define the number of surfaces and one surface may be exposed to GAS (i.e., AIR or liquid vapor). At any surface the LIQUID will have stress and strain expressed by one of the phenomena: SURFACE TENSION.

Surface Potential Energy

[biomedical, chemical, computational, fluid dynamics, mechanics, thermodynamics] Theoretical model of the ENERGY configuration of a system, specifically atoms with respect to their arrangement. The concept is used primarily in computational chemistry. The surface potential energy, also known as potential energy surface, defines the relationship between the energy configuration of a MOLECULE and the geometry of the molecule, either in graphical format or mathematically. The graphical representation for instance represents the potential energy for a molecule as a function of the bond-length and the ANGLE of the atomic bond. In molecular MECHANICS the potential surface energy described the molecular energy with respect to bending, TORSION, stretching, and so on. Under QUANTUM mechanical approach the energy function outlines the work effort with respect to the SCHRÖDINGER WAVE EQUATION. The two-dimensional energy surface can illustrate the atomic configuration (bond length and bond angle) that is more susceptible to chemical interaction: transition state. This model does not account for the inherent incessant vibrations of the molecule, neither for deviations from equilibrium. Under equilibrium conditions the SCHRÖDINGER EQUATION for the molecule can be solved by assuming a simple HARMONIC OSCILLATION (with spring constant k) around equilibrium (interatomic equilibrium DISTANCE $\vec{q}_e$) in the direction of the connecting line of the interatomic bond links ($\vec{q}$); using $E = (1/2)k(\vec{q} - \vec{q}_e)^2$. This potential

energy is however not valid when the atomic separation is far from equilibrium length. The potential energy levels off, drops off, with increasing separation on the bond-length. In QUANTUM MECHANICS the molecular Hamiltonian is defined by the ATOMIC NUMBER (Z) and respective distances between nuclei (R_{12} [fixed]; r_{1i} ; r_{ij} , electron orbits: i, j) within the molecular structure and respective molecular constituents (i ; 2 ; mass m_i) as $\hat{H} = -(1/2)\sum_i \nabla_i^2 - \sum_i (1/2m_i)\nabla_i^2 - \sum_{1,i} (Z_1/r_{1i}) + \sum_{1>2} (Z_1Z_2/R_{12}) + \sum_{i>j} (1/r_{ij})$, where the term $V_{eN}(\vec{r}, \vec{R}) = -\sum_{1,i} Z_1/r_{1i}$ represents the electron (e) nuclear potential energy (N DEGREES OF FREEDOM). The SURFACE ENERGY potential prevents the Hamiltonian from being separated. Without surface potential energy the Hamiltonian is separable with energy eigenvalues: $E = E_A + E_B$, and eigenfunctions: $\Psi(q_1, q_2) = \Psi_A(q_1)\Psi_B(q_2)$; $\hat{H}_A(q_1)\Psi_A(q_1) = E_A\Psi_A(q_1)$, and $\hat{H}_B(q_2)\Psi_B(q_2) = E_B\Psi_B(q_2)$. The electron–nuclear potential inherently ties the electronic degrees of freedom to the nuclear degrees of freedom. The potential energy surface applies to the molecular dimension (R) as $\hat{H}_e(\vec{r}; \vec{R})\Psi(\vec{r}; \vec{R}) = E_e(\vec{R})\Psi(\vec{r}; \vec{R})$ (also see BORN–OPPENHEIMER APPROXIMATION) (see Figure S.129).

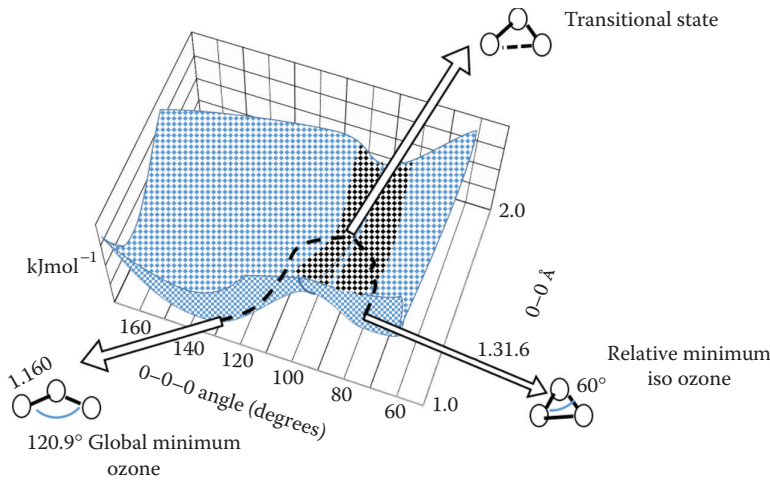


Figure S.129 Graphical representation of Surface potential Energy.

Surface roughness

[acoustics, fluid dynamics, mechanics] Unevenness in the profile of a system, either object, channel (river) or PIPE. The ROUGHNESS defines the absolute or relative deviations from ideally smooth for a segment or with respect to the attainable effects resulting from a surface treatment or construction technique, next to the choice of material (e.g., ceramics vs. wood vs. metal). Commonly used surface parameters are: roughness area $R_a = 1/n \sum_{i=1}^n |z_i|$ (z_i the localized deviation from perfect flat, measured in n locations); root-mean-squared roughness $R_q = \sqrt{(1/n \sum_{i=1}^n z_i^2)}$; or with respect to the maximum allowable height of the imperfections. More detailed, in three dimensions: $R_a = 1/mn \sum_{k=0}^{m-1} \sum_{\ell=0}^{n-1} |z(x_k, y_\ell) - \mu_{ave}|$, $\mu_{ave} = 1/mn \sum_{k=0}^{m-1} \sum_{\ell=0}^{n-1} z(x_k, y_\ell)$ representing the preferred level (e.g., radius) or average. Additional parameters used in defining the surface profile, as for instance used in design drawings (CAD drawings) is the slope of the unevenness by means of deviation from level under ANGLE α : $R_{dq} = \sqrt{(1/n \sum_{i=1}^n \alpha_i^2)}$ or $R_{da} = 1/n \sum_{i=1}^n |\alpha_i|$. The angular deviations are determined from surface elevation iterations. One standard compares unevenness as a function of linear location x as $\alpha_i = 1/60 dx (z_{i+3} - 9z_{i+2} + 45z_{i+1} - 45z_{i-1} + 9z_{i-2} - z_{i-3})$, around flat z_i . The latter would apply to machining instructions such as turning a rod on a lathe. These parameters are set under industry standards implemented by professional organizations such as American Society of Mechanical Engineers (ASME) or ISO STANDARDS (International Organization for Standardization). Surface finish contributes to the FRICTION between two surfaces as well as the influence on the formation of BOUNDARY LAYER effects during flow. The three-dimensional configuration of a surface can be examined by atomic force microscopy, Optical interference profilometry scanning (e.g., OPTICAL COHERENCE TOMOGRAPHY) or Scanning Electron

Microscope on MICROSCOPIC level, or by surveying tools on MACROSCOPIC scale. Controlling the roughness can result in expensive processes, increasing the final price/cost for the device. In general during design the surface roughness is specified with acceptable tolerance for the specific goal of the use of the material, device or structure. Optical devices are specified in surface treatment with respect to the wavelength (λ), not more deviation than a fraction of the average or standard wavelength. Also referred to as roughness. May also be described as surface texture (see [Figure S.130](#)).

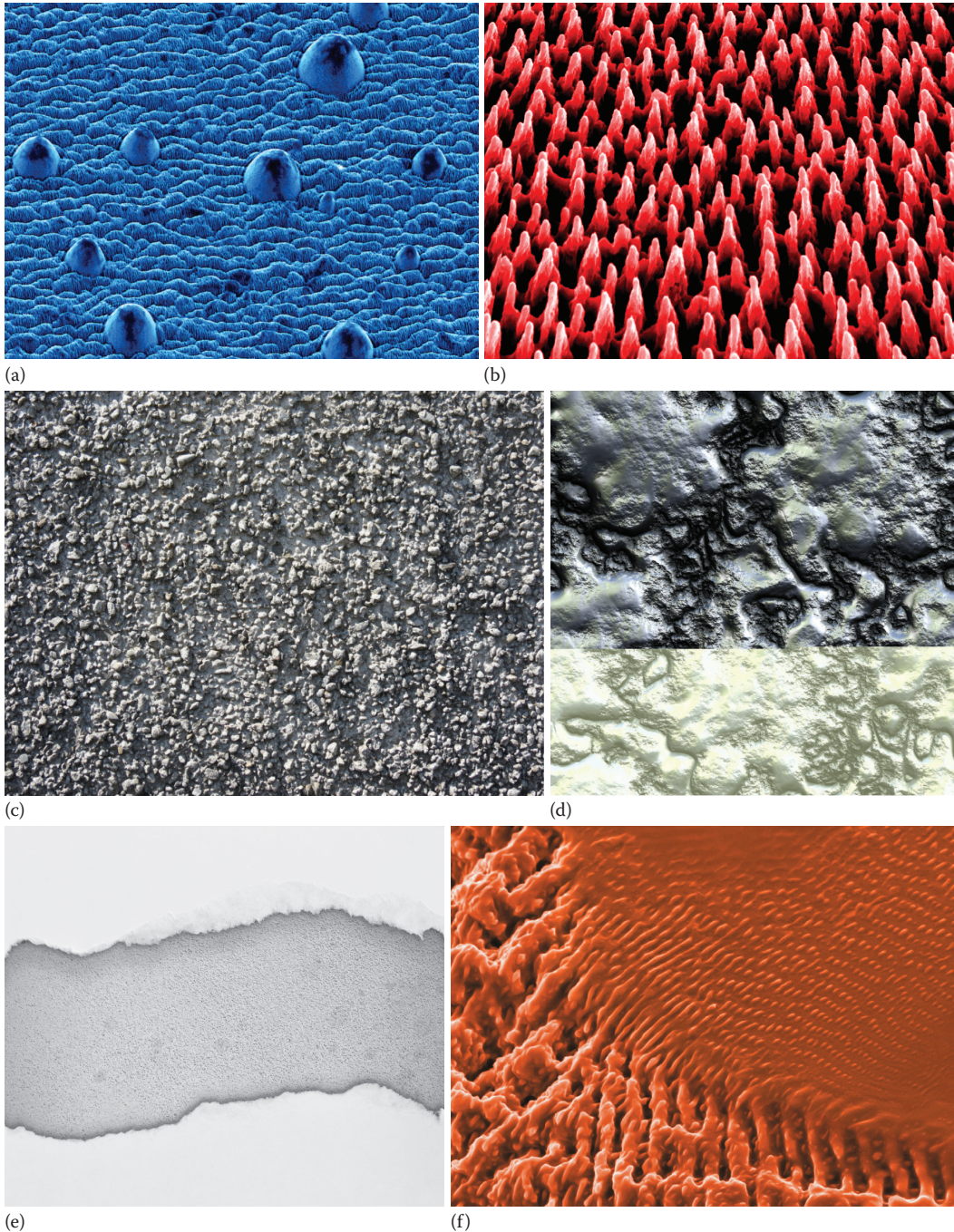


Figure S.130 (a–f) Surface roughness.

Surface tension

[biomedical, chemical, fluid mechanics, mechanics, thermodynamics] Stress in the SURFACE of a LIQUID, equivalent to the WORK (i.e., force $[F]$ multiplied by displacement $d\ell$ given as $W = Fd\ell$) per unit area to change the size of the area (dA) (increase, work performed by decrease; most liquids at most TEMPERATURE ranges): $\sigma_{\text{surface}} = Fd\ell/dA$. For a cord or rod confining a soap film the area can for instance be expressed as $dA = 2Ld\ell$, since the demarcation between the film and outside has a length on both sides of the BARRIER. Physical equivalence in a SKIN stretched over a hoop, for instance for a musical drum. A surface layer may be on a continuous medium or film (e.g., soap BUBBLE). Surface tension is generally independent of the layer thickness, reducing the effect to a molecular phenomenon (i.e., VAN DER WAALS FORCE). Surface tension on a droplet will confine a medium by force, hence the pressure (VAPOR PRESSURE) inside the droplet will always be greater than the outside pressure. The surface tension on a single surface medium is defined by the LAPLACE LAW. One specific exception to the single surface is in the ALVEOLI of the LUNG. Another surface tension phenomenon is in the boundary between a vessel and the surface of a liquid. Liquids may adhere to the vessel surface ("wet the surface of the container") or be repelled by the container WALL ("liquid does not wet the surface"). When the liquid ADHESION (i.e., COHESION) is strong the liquid will form a negative meniscus, in case the adhesion to the vessel is stronger than the cohesion of the liquid the liquid will form a positive meniscus. One specific example is water in a glass beaker. Since glass is polar it will tend to attract the polar water molecules applying grease to the wall of the beaker will separate the polar attraction by the GLASS from the cohesive Vander Waals force and the MENISCUS will flip negative. A positive meniscus is often an indication that there is potential for the liquid to actively CREEP up the wall. The creep is especially noticeable in a narrow tube, creating CAPILLARY ACTION, making the liquid climb the wall of the tube for a considerable DISTANCE, depending on the tube diameter and the density of the liquid. Contact ANGLES for some interfaces vary as a function of temperature. Wetting liquids on a clean surface (i.e., water on glass) will continue to spread until the water has reached molecular thickness (i.e., MONOLAYER). Surface tension can be broken by means of chemical binding (dissolve the chemical based on the match in polar nature, whereas OIL is very nonpolar) with a SURFACTANT, such as ordinary soap (see Figure S.131).

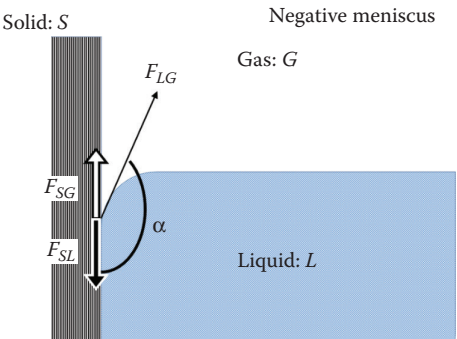


Figure S.131 Surface tension: tension between liquid and solid surface of container.

Most organic liquids—glass	0°–10°
Mercury—copper	0°
Pure water—glass	0°
Water—glass	20°
Kerosene—glass	26°
Water—silver	90°
Water—parafin	106°
Mercury—glass	148°

Surface waves

[fluid dynamics] Waves on the surface of a medium (primarily liquid, alternative approach for solids) generated from equilibrium (*also see* WAVE EQUATION, for general theoretical description of periodic motion). Surface waves can result from wind blowing over the waver surface, or as a result of EARTHQUAKE (i.e., TSUNAMI). This phenomenon is governed by the CONSERVATION LAWS in the form of the Euler equations for a medium with constant density: $\rho = \rho_0$. The VELOCITY POTENTIAL (ϕ) for a two-dimensional plane-wave with displacement in the y -direction, propagating in the x -direction will be irrotational and satisfies the condition: $(\partial\phi^2/\partial x^2) + (\partial\phi^2/\partial y^2) = 0$, with the condition $\partial\phi/\partial n = 0$. This is described by the Cauchy-Poisson wave equation. The vertical displacement (i.e., MOTION around equilibrium level) as a function of linear direction of propagation is given as $b(x, t) = 1/\pi x \{ (gt^2/2x) - (1/3 \times 5)(gt^2/2x)^3 + (1/3 \times 5 \times 7)(gt^2/2x)^5 - \dots \}; (gt^2/2x) \ll 1$, with a constant acceleration of the PHASE of the WAVE given as $a_{pb} = (g\pi A_w/\lambda) [\cosh(2\pi^{b_a+b(x,t)/\lambda})] / [\cosh(2\pi^{b_a/\lambda})] \sin((2\pi x/\lambda) - (2\pi t/T))$, where g the GRAVITATIONAL ACCELERATION, A_w is the wave AMPLITUDE, b_a is the average depth of the water or the average DISTANCE from the solid bottom to the surface of the FLUID in motion, T the wave period and λ the wavelength. Generally, for a small displacement the surface motion can be described by a FOURIER SERIES as a sine and cosine sum (*see* WAVE EQUATION). The surface wave propagation in fact stretches the wave pattern out as it propagates with wavelength: $\lambda = 8\pi s^2/gt^2$ with t the elapsed time. The surface-wave itself propagates with the group velocity: $v_g = 0.5c(1 + (2kb_a/\sinh 2kb_a))$, where $c = \sqrt{(g/k)\tanh kb_a} \cong \text{Constant}$, at constant depth (b_a , the average surface height from the seafloor), and $k = 2\pi/\lambda$ is the wavenumber. Note that for example, the wave breaking on the surface is the result of a nonlinearity in the acceleration, the DISPERSION in this case is the direct result of a difference in linear acceleration on the surface as a function of both wavelength and depth defined by $a = dv_g/dt$. Alternatively: $b(s, t) \cong \sqrt{g} t^2/\rho 2^{5/2} \pi^{1/2} s^{5/2} \{ \cos(gt^2/4s) - \sin(gt^2/4s) \}; (gt^2/2s) \geq 1$, where s is the path of propagation. The PHASE VELOCITY of surface waves is gives as $v_{pb} = \sqrt{((g\lambda/2\pi) + (2\pi T_s/\rho\lambda)) \tanh(2\pi b_a/\lambda)}$, where T_s is the LIQUID surface tension, ρ the liquid density. (p36 Fundamentele Natuurkunde, deel 3 Golven; Alonso & Finn//Fundamental University Physics #3.) Since the phase velocity is apparently a function of the wavelength a phenomenon known as WAVE DISPERSION will occur. Under dispersion the complex wave constructed of the superposition of multiple waves with a range of frequencies will deform in the process of propagation in the dispersive medium. The deformation results from the different velocities of the respective spectral components of the complex wave. The phase velocity of surface waves can be derived under condition that the wave amplitude is sufficiently small using linear theory providing for deep water: $v_{pb} = \sqrt{(g/k)}$; $b(s, t) > 0.4\lambda$, and for shallow water: $v_{pb} = \sqrt{((g\lambda/2\pi)(2\pi b/\lambda))} = \sqrt{gb}$; $b(s, t) < 0.04\lambda$ (*see* Figure S.132).



Figure S.132 Surface wave resulting from earthquake causing destruction due to vibration.

Surfaces of discontinuity

[fluid dynamics] See DISCONTINUOUS MOTIONS.

Surfactant

[biomedical, chemical, fluid mechanics, mechanics, thermodynamics] Chemical medium that has as property to lower the SURFACE TENSION of a FLUID when mixed or applied to the surface. Soap/detergents is a surfactant, designed to modify the tension between two media, for example, lowering the ADHESION of loose material from a solid (e.g., food on plate; dirt on clothing). Wettings agents and detergents generally have a molecular structure that is hydrophobic on one side and hydrophilic on the opposite side (amphiphilic). A surfactant may also be designed to have a nonlinear relation to the surface area (specifically applied to spherical configuration), defying the LAPLACE LAW. In the lungs the surfactant on the inside of the alveoli is specifically that way, made of six lipids and four proteins, adjusting to the size of the alveoli for optimal oxygen transfer between the AIR in the lung and the CELL layer. Lung surfactant is produced between week 24 and 28 of gestation. Premature babies (prior to week 35) often require surfactant replacement therapy to ensure proper VENTILATION of oxygen and carbon-dioxide. Lung surfactant can be produced artificially under synthetic circumstances (see [Figure S.133](#)).

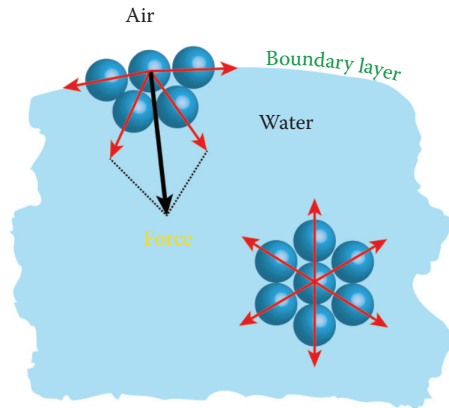


Figure S.133 Surface forces diagram.

Synapse

[biomedical, chemical] Chemical transponder between nerve CELL (at the terminal end of an axon or dendrite) that releases chemicals upon excitation by an action potential. The release of the specific chemicals are correlated to the function and location of the nerve-cell and are a chemical mediator to induce a chemical imbalance at the synapse across from the junction that will lead to a trans-membrane potential resulting in the initiation of an action-potential in the next link of SIGNAL transport to reach the final destination,

either MUSCLE, brain or specific chemical organ (e.g., digestive or regulatory in the form of BLOOD acidity) (See NERVE) (see [Figure S.134](#)).

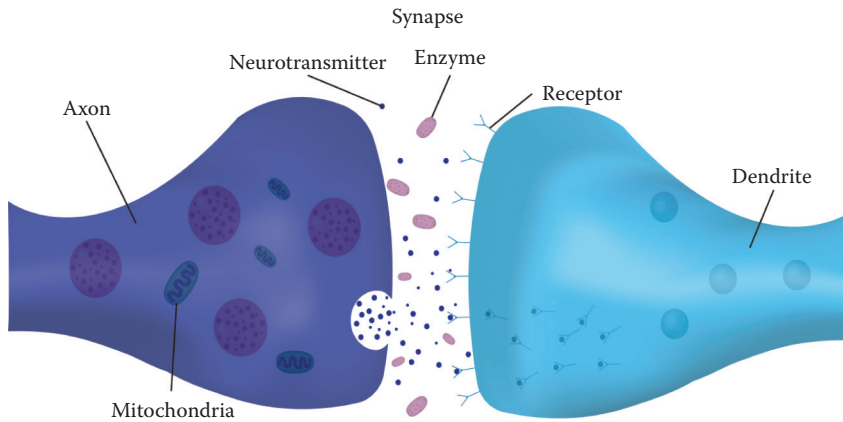


Figure S.134 Synapse.

Synaptic signaling

[biomedical, chemical, energy] Secretion of signaling molecules (i.e., NEUROTRANSMITTERS) between neurons. The chemical exchange initiates an ACTION POTENTIAL in all the neurons connecting at the “router-station.” Signals can be amplified in this manner by exciting multiple neurons and hence increasing the communication channels to one or multiple terminal locations in the sympathetic and PARASYMPATHETIC NERVE SYSTEM as well as the brain and brain-stem (see [Figure S.135](#)).

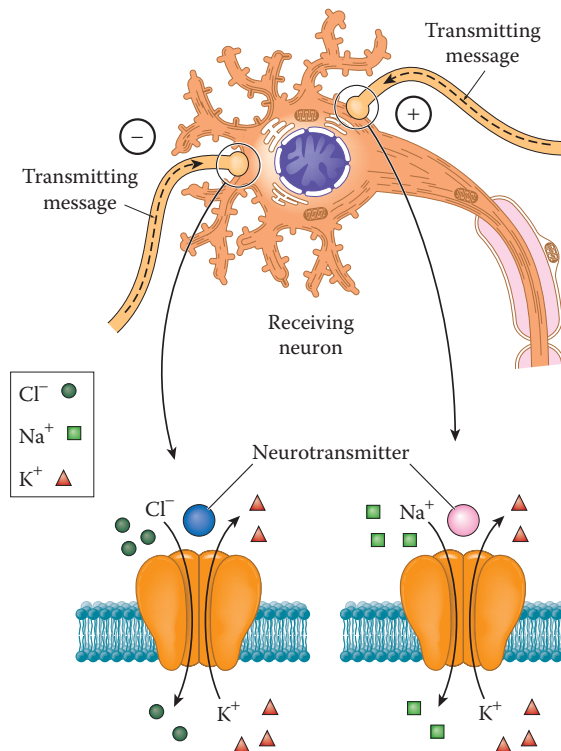


Figure S.135 Synaptic signaling.

Synchrotron

[astronomy/astrophysics, atomic, energy, nuclear] **Linear PARTICLE ACCELERATOR**. The largest linear accelerator is at the European Organization for Nuclear Research; CERN facility ("Conseil Européen pour la Recherche Nucléaire" French) at the border between Switzerland and France. The CERN SYNCHROTRON can reach kinetic energies for protons in excess of 10^3 GeV, simultaneously for in the order of 10^{13} protons (see [Figure S.136](#)).



Figure S.136 Synchrotron. (Courtesy of Fermi National Accelerator Laboratory [Fermilab], Batavia, IL.)

Synchrotron radiation

[astronomy/astrophysics, atomic, energy, nuclear] **RADIATION** emitted by a charged **PARTICLE** when accelerated around a curved path, change in direction. In comparison, every charged particle under linear acceleration will emit electromagnetic radiation.

Systolic pressure

[biomedical] Pressure achieved by the full contraction of the **HEART**. The maximum pressure applied to **BLOOD** ejection into the compliant vascular system of the biological body. High level pressure is measured by the **SPHYGMOMANOMETER**. The auscultation technique involves wrapping an inflatable cuff around the elbow of the arm and inflating the external pressure above any reasonably known high systolic pressure, and subsequently systematically reducing the applied pressure to balance with the pressure in the tissue applied to the brachial artery in order to listen for the **KOROTKOFF SOUNDS**. In combination with the **DIASTOLIC PRESSURE** these are some of the vital signs acquired during a routine visit to the doctor's office, next to heart-rate and body temperature. The aortic pressure fluctuates between the systolic and the diastolic pressure with each heartbeat. In case any of these show deviations from the norm additional diagnostic techniques may involve obtaining an **ELECTROCARDIOGRAM (ECG)**, next to further analysis of the respiratory system with breathing exercises. A variety of physical and psychological reasons can result primarily in a change in systolic, and secondary in diastolic, pressure. One of the most common causes for **BLOOD PRESSURE** variability is general

heart disease, followed in second place by reduction in vascular COMPLIANCE or respectively an increase in RESISTANCE for the down-stream fluid-dynamics system (the CIRCULATION) (see [Figure S.137](#)).

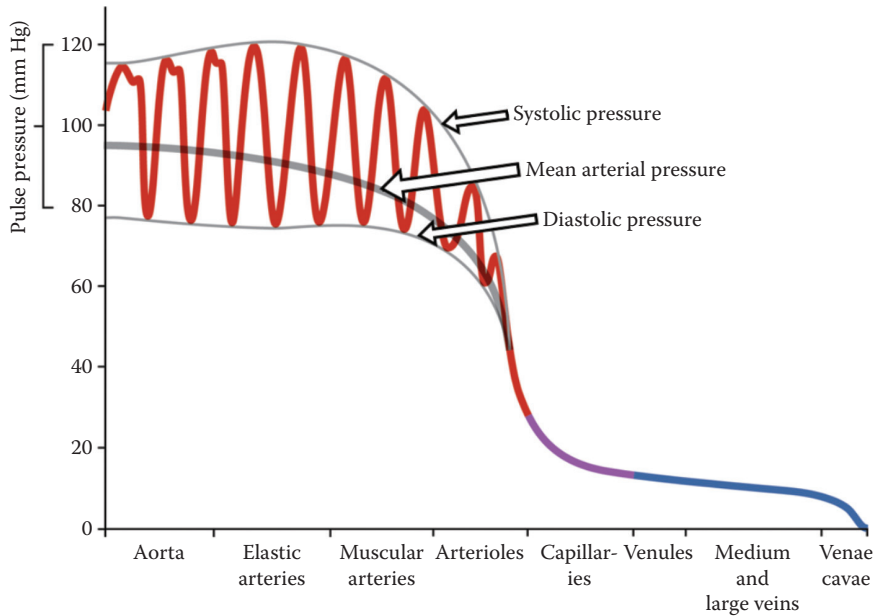


Figure S.137 Systolic pressure of the human heart obtained during contraction, facilitating pumping action.



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't Hooft, Gerard {Geradus} (1946–)

[atomic, general, solid-state] Scientist from the Netherlands. 't Hooft made his first contribution as a graduate student in 1969 on the Yang–Mills gauge fields, showing how they could be renormalizable; thus formulating the concept of renormalization (see [Figure T.1](#)).

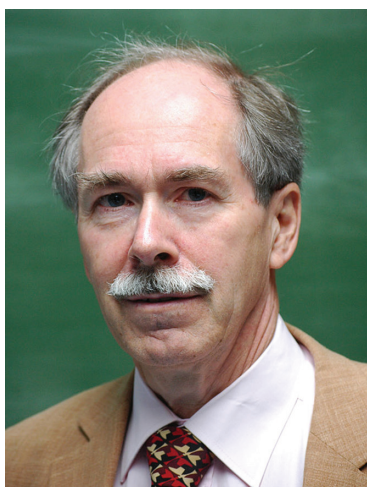


Figure T.1 Gerard 't Hooft (1946–).

Tachyon

[general, quantum, relativistic] Hypothetical massless PARTICLE that moves at velocities greater than the speed of LIGHT. In current theoretical context, a velocity faster than the speed of light under special relativistic doctrines will violate the causality principles. The tachyon concept was introduced by Olexa-Myron Bilaniuk (1926–2009), VIJAY DESHPANDE (mid-twentieth century–), and George Sudarshan (1931–) in 1962. In this assumption, the ENERGY is thought of as imaginary, avoiding the relativistic rest-mass constraints: $E^2 = p^2 c^2 + m^2 c^2$, where $p = mv$ the momentum, v the velocity, m the mass, and $c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8$ m/s the speed of light.

Tacoma Narrows Bridge

[general] Infamous bridge in the Washington state of the United States that had a design of suspension cables. The bridge spanned across the Tacoma Narrows strait of Puget SOUND. The suspension cables were subject to wind blowing in from the Pacific Ocean. Under specific conditions, the wind was able to bring the cables into

VIBRATION. At one time, the vibrations of the cables matched the RESONANCE vibration frequency of the main bridge, causing the entire bridge to oscillate, eventually leading to mechanical failure in 1940. The failure occurred only months after the completion of the bridge's construction (*also see* RESONANCE) (see [Figure T.2](#)).



Figure T.2 Tacoma Narrows Bridge under oscillation resulting from the Aeolian sounds generated by the wind stroking the suspension cables.

Tait, Peter Guthrie (1831–1901)

[general] Scientist from Scotland, Great Britain, contemporary and colleague of LORD KELVIN (1824–1907), WILLIAM HAMILTON (1805–1865), and JAMES CLERK MAXWELL (1831–1879). The work of Guthrie Tait focused on general PHYSICS, and he introduced several mathematical treatments and definitions for general physics concepts, specifically MECHANICS (see [Figure T.3](#)).



Figure T.3 Peter Guthrie Tait (1831–1901).

Tangential acceleration (a_T)

[general, mechanics] Acceleration associated with the revolution of an object and the associated change of angular velocity (direction and MAGNITUDE): $\alpha_c = a_T / r$, with a_T the tangential acceleration, r the radius from the center of the revolution, and the centripetal acceleration, changing the tangential ANGULAR VELOCITY (ω) as a function of time (t): $\alpha_c = d\omega/dt = d^2\theta/dt^2$, θ the ANGLE of rotation. The tangential acceleration forms a counterforce to maintain circular MOTION (see Figure T.4).

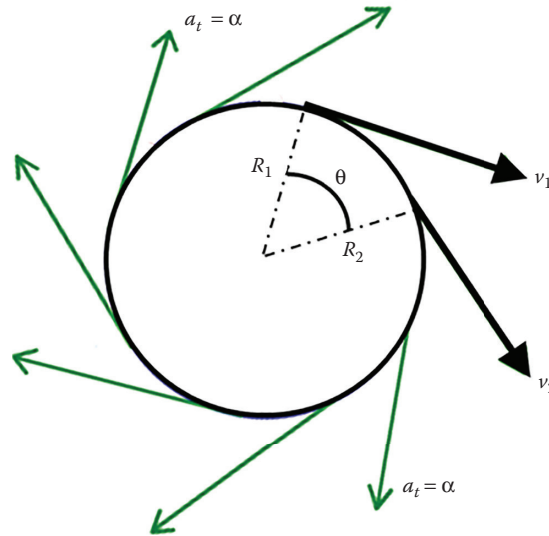


Figure T.4 Tangential acceleration, changing the direction of the constant velocity of revolution.

Tangential stress

[fluid dynamics, mechanics] Angular or circumferential STRESS (stress holding the shear for the potentially expanding “shell of the medium.” In contrast to shear stress that is parallel to the plane of the material CROSS SECTION. Alternatively, normal stress is applied perpendicular to the material cross section. In tubes there are generally three stresses to be considered: longitudinal stress, radial stress, and hoop or tangential stress. Hoop stress is a tangential stress, in the circumferential direction. The hoop stress, specifically for a thick-walled tube, at any location r within the WALL of the tube with an inner radius r_i , outer radius r_o , wall thickness $d = r_o - r_i$ is $\sigma_{c, \text{thick}} = [(P_i r_i^2 - P_o r_o^2) / (r_o^2 - r_i^2)] - [r_i^2 r_o^2 (P_o - P_i) / r^2 (r_o^2 - r_i^2)]$. Alternatively for a

thin-walled tube (e.g., balloon; “holding the balloon together”) the tangential stress is $\sigma_{e,\text{thin}} = P_i r_i / d$, also known as SHEAR STRESS (see Figure T.5).

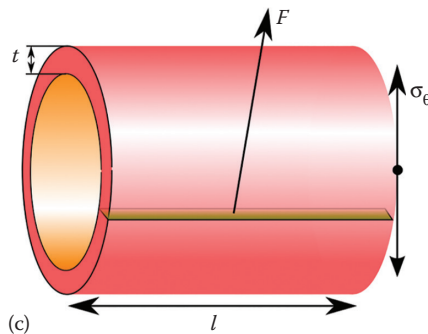
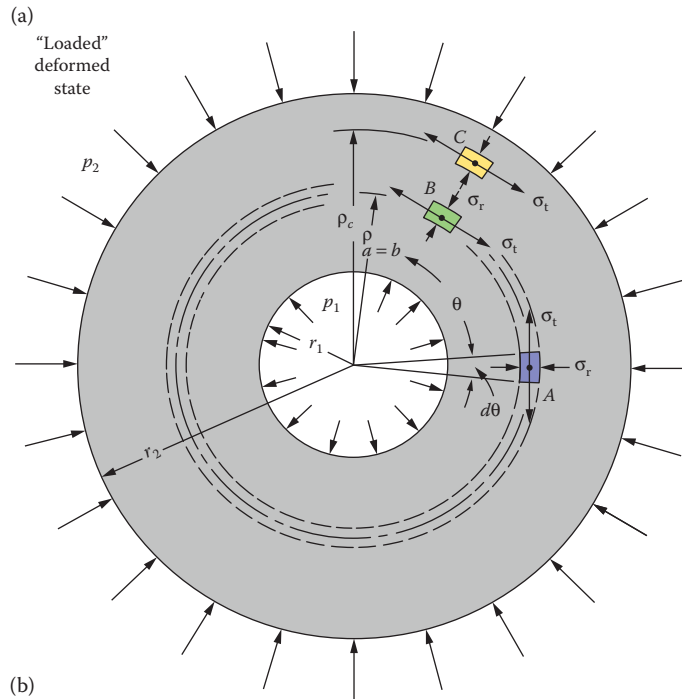
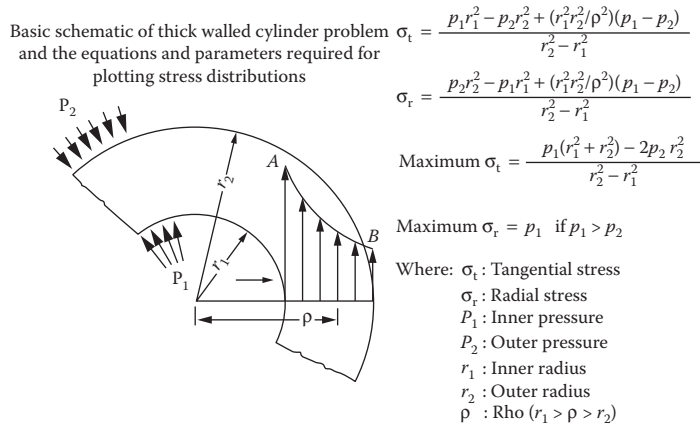


Figure T.5 (a–c) Tangential stress, for instance on blood vessel. (a,b: Courtesy of Dr. Romesh Batra; Virginia Polytechnic Institute, Blacksburg, Virginia.) (c: Courtesy of Häggström, Mikael. “Medical gallery of Mikael Häggström 2014.”)

Tate, John Torrence, Jr. (1925–)

[chemical, general, mechanics] Scientist and mathematician from the United States. Tate provided a wealth of information with regard to tension, specifically SURFACE TENSION, and THERMODYNAMICS (see [Figure T.6](#)).

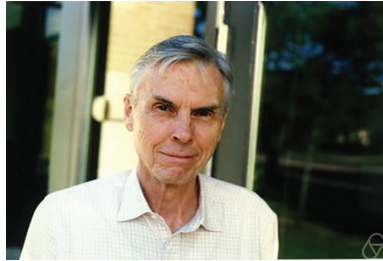


Figure T.6 John Torrence Tate, Jr. (1925–), photograph by George M. Bergman.

Tate, John Torrence, Sr. (1889–1950)

[general, mechanics] Physicist from the United States, father of JOHN TORRENCE TATE, JR. (1925–) (see [Figure T.7](#)).



Figure T.7 John Torrence Tate, Sr. (1889–1950).

Tate's law

[general, mechanics] Boundary condition in droplet formation, for a LIQUID with mass m_{liq} , subject to a SURFACE TENSION (as may be described by the Marangoni surface tension T_s) the droplet will detach from the stream when the surface curvature reached $\chi = 90^\circ$, or that the droplet confinement needs to satisfy: $m_{\text{liq}}g \leq 2\pi r_{\text{stream}} T_s \sin \chi$, which yields $m_{\text{liq}}g = 2\pi r_{\text{stream}} T_s$, where r_{stream} is the radius of the FLUID stream, or the radius of a CAPILLARY tube, and g the GRAVITATIONAL ACCELERATION. As defined in 1864 by JOHN TORRENCE TATE, SR. (1889–1950) and applied in the stalagmometer device to measure surface tension, T . Tate introduced this equation to define the MAGNITUDE (diameter and weight) of a drop of liquid.

Tau lepton

[general] Long-lived elementary PARTICLE; lifetime: $4.6 \pm 1.9 \times 10^{-13}$ s. One of the six (6) recognized and identified leptons: electron, NEUTRINO (e): ν_e , MUON: μ^- , NEUTRINO (μ): ν_μ , tau: τ , and neutrino (τ): ν_τ . The tau lepton has the shortest lifetime of all leptons, with the muon second (2.197×10^{-6} s) and the rest stable. Also known as the tau (see [Figure T.8](#)).

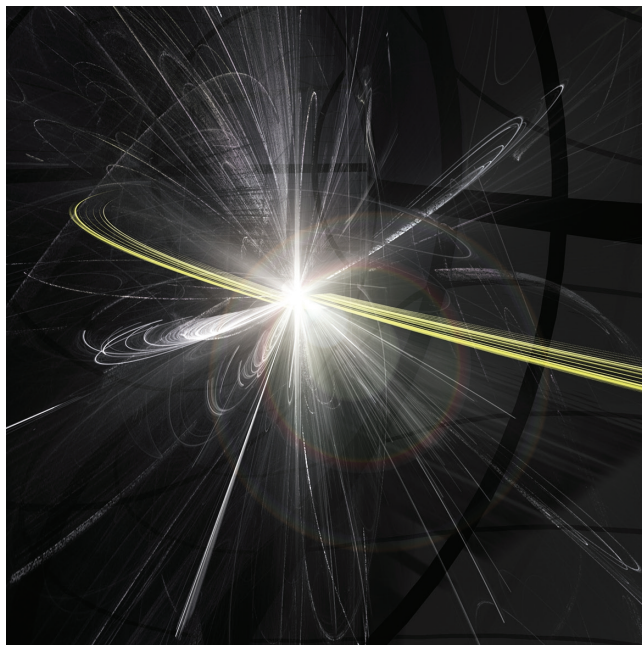


Figure T.8 Collision experimental design with Large Hadron Collider in Switzerland in search of the tau lepton.

Taylor, Brook (1685–1731)

[computational] Mathematician from Great Britain. Brook Taylor is best known for the Taylor Series, published in 1715 (see [Figure T.9](#)).



Figure T.9 Brook Taylor (1685–1731), painting by Louis Goupy.

Taylor, Geoffrey Ingram, Sir (1886–1975)

[computational, fluid dynamics, nuclear] Scientist and mathematician from Great Britain. Sir Geoffrey Taylor provided computational evidence of the Young double slit experiment based on the WAVE theory. Sir Taylor also contributed significantly to the development of PROPELLER blades, based on the fluid-dynamic aspects. Additional work was on the electric discharges under thunderstorms (see [Figure T.10](#)).



Figure T.10 Sir Geoffrey Ingram Taylor (1886–1975).

Taylor dispersion

[biomedical, fluid dynamics] Radial DISPERSION of a SOLUTE during an axial LAMINAR FLOW through a straight tube (the radius of curvature: infinity) with a circular CROSS SECTION. However, the principle also applies to curved conduits, more specifically in a bifurcated arterial and venous flow in the biological CIRCULATORY SYSTEM. Analogous applications can be derived for a turbulent flow as well. Based on the work by SIR GEOFFREY INGRAM TAYLOR (1886–1975). The FLUID flow for a PIPE with radius R , in the z -direction with the flow velocity in the z -direction w , distributed over a radius r has a velocity profile defined by $\vec{u} = w_0 [1 - (r^2/R^2)] e_z$, where e_z is the unit vector in the z -direction. For a solute, the DIFFUSION associated with this flow is defined by $(\partial[C]/\partial t) + \vec{u} \cdot \nabla[C] = D_{\text{diff}} \nabla^2[C]$, with $[C]$ the chemical concentration and

D_{diff} the DIFFUSIVITY. The diffusivity is linked to the Péclet number (Pe_d) through the effective diffusivity: $D_{\text{diff,eff}} = D_{\text{diff}} \left[1 + (1/192) Pe_d^2 \right]$, which indicates that the TAYLOR DISPERSION (the shear effect on the disbursement of the chemical concentration in the direction of flow) is more pronounced for a higher Péclet number (e.g., formation of “Taylor vortices”).

Taylor expansion

[computational] Discrete representation of a function as an infinite sum of derivatives of the function itself in a single point and was introduced by the British mathematician BROOK TAYLOR (1685–1731) in 1715, based on the work on curves and geometry by the Scottish astronomer and mathematician JAMES GREGORY (1638–1675) in 1668. Also known as TAYLOR SERIES.

Tectonic plates

[geophysics, mechanics] Concept introduced and validated in the 1960s considering the continents to be located on individual lithospheric plates of approximately 150 km thickness that apparently float on the magma of the ASTHENOSPHERE (see [Figure T.11](#)).

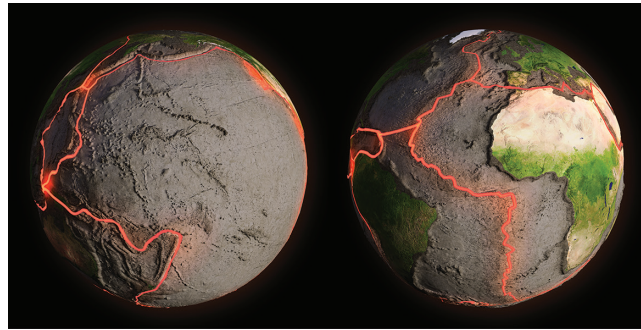


Figure T.11 Tectonic plates and fault-line between tectonic plates.

Tectonics

[acoustics, astrophysics/astronomy, chemical, electromagnetism, fluid dynamics, geophysics, mechanics, solid-state, thermodynamics] The study of the physical phenomena and processes of a planet's crust (*also see* EARTHQUAKE and SEISMIC) (see [Figure T.12](#)).

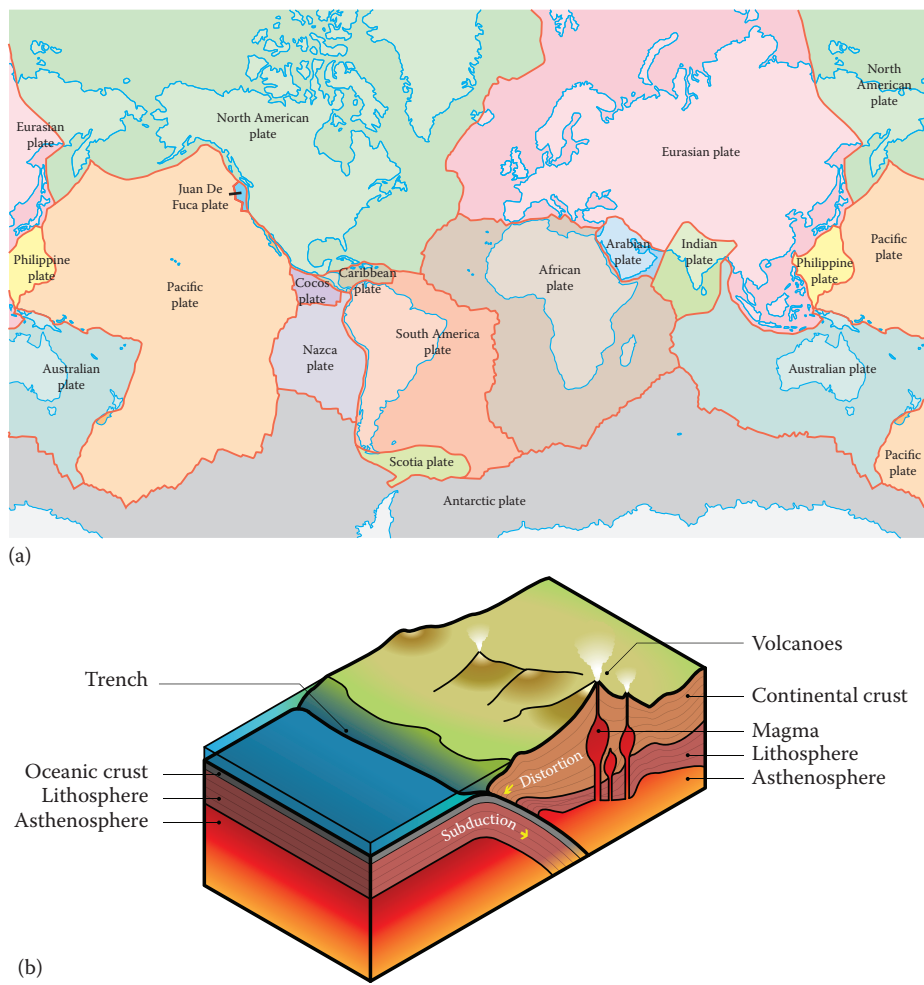


Figure T.12 (a) Types of tectonic plate boundaries and (b) diagram illustrating plate subduction.

Teflon®

[biomedical, chemical, mechanics] Brand name for polytetrafluoroethylene (PTFE), a synthetic fluoropolymer of tetrafluoroethylene; registered trademark from the DuPont corporation, discovered in

1938 by the chemist from the United States Roy Plunkett (1910–1994). The high MOLECULAR WEIGHT material has a very low coefficient of FRICTION; this will result in an extremely low degree of static and KINETIC FRICTION with respect to virtually any material. Teflon has a high stability temperature and is hence used as a nonstick coating for a broad range of industrial and commercial applications (e.g., pots and frying pans). The additional mechanical and chemically inert properties have provided ample applications as tape and gasket material (see [Figure T.13](#)).



Figure T.13 Burj Al Arab hotel in Dubai with a Teflon-coated screen that encloses the three sides of the Burj al Arab atrium. The screen covers a surface area of several hundred square meter and is made of glass fiber fabric with a thickness of approximately 1 mm; the Teflon® is intended to stop dirt from sticking to it.

Telegraph

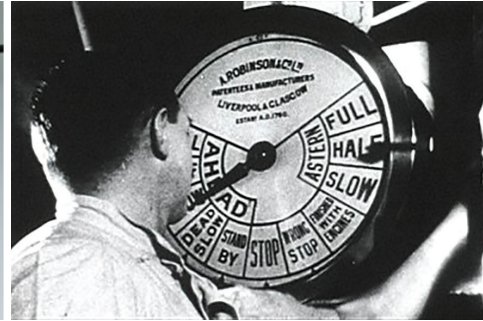
T

[computational, electric, general] Device used for the decoding of information in a binary fashion and transmission by electrical means. The device was initially designed in 1792 by Claude Chappe (1763–1805), an engineer from France who also introduced the term “telegraph.” Claude Chappe started out with the semaphore concept, which uses an optical SIGNAL for conveying messages over great distances, either by the position of mechanical arms (also used in the Netherlands with the position of the blades/sails of the windmills, dating back to the seventeenth century), or towers with pivoting shutters. Subsequently SAMUEL FINLEY BREESE MORSE (1791–1872), a painter and inventor from the United States introduced the MORSE CODE for communication of succinct messages. The efforts of Samuel Morse led to the commercial proliferation of a consumer device. The later mathematical design is based on the mathematical and electronic efforts of the engineer Oliver Heaviside (1850–1925) from Great Britain. Note that semaphores

are still used for signaling in train traffic as well as directing traffic by police officers, and traffic LIGHT is also a clear example of semaphores (see [Figure T.14](#)).



(a)



(b)



(c)

Figure T.14 (a) Telegraph machine and operator and (b) old design ship communication telegraph. The device would “ping” a bell to indicate the desired operating instructions; for example, “full steam ahead.” (c) Example of modern rail traffic controlling semaphore device.

Telegraph equation

[biomedical, computational, energy, fluid dynamics] Mathematical differential equation describing the propagation of a periodic phenomenon (e.g., WAVE), developed by the scientist and engineer from Great Britain Oliver Heaviside (1850–1925). In electrical ENGINEERING, the telegraph equation describes the propagation of a harmonic wave over a conducting cable for analog data transmission.

The electrical potential (U_{pot}), which varies with time, is a function of the propagation path length ($d\tilde{z}$) and a function of TIME (t) as can be found by solving a one-dimensional differential equation: $(1/LC)(d^2U_{\text{pot}}/d\tilde{z}^2) = (d^2U_{\text{pot}}/dt^2) + [(R/L) + (\mathbb{R}/C)](dU_{\text{pot}}/dt) + (\mathbb{R}R/LC)U_{\text{pot}}$, where $\mathbb{R}$ represents the conductivity over a length of schematic. Alternatively for a conducting medium with properties inductance (L), capacitance (C), and RESISTANCE (R): $(d^2V_m/dt^2) - (c_1 + c_2)(dV_m/dt) = c_3^2(d^2V_m/d\tilde{z}^2) + c_1c_2V_m$, where $c_1 = (1/C_m)(1/R_m d\tilde{z})$, $c_2 = R_p/L_p$, and $c_3^2 = 1/L_p C_m$, with $\tilde{z}$ the direction of propagation along the length of the CELL (axon), and $\square_p$ and $\square_m$ with respect to the direction of propagation and the boundary ("shell" of the CONDUCTOR), respectively. The potential migration reduces to $d^2V_m/dt^2 = c_3^2(d^2V_m/d\tilde{z}^2)$ in the absence of resistance and electron/ionic leak current (e.g., POLARIZATION of either the insulating layer surrounding the cable or external FLUID or LIQUID), which is a plain HARMONIC OSCILLATION. Next to electronic transmission, the propagation of a wave pulse in liquid in FLUID DYNAMICS can be analyzed by implementing a perturbation on a steady-state axial flow $u(r, t)$ to derive the DISPERSION and frequency-dependent flow from developing the expression in a harmonic expansion by means of a Poisson series as $u(r, t) = u'(r)e^{i\omega_n t}$, ω_n represents the harmonics in the frequency pattern of the PULSATILE FLOW. This time-dependent expression can be substituted in the Poiseuille equation, providing the flow dynamic equivalent of the telegraph equation for the flow velocity as a function of radius and time as well as axial location: $u(\tilde{r}, t) = \text{Re}\{-(ia_n/\omega_n)e^{i\omega_n t}[1 - J_0(\sqrt{-i}\alpha(r/R))/J_0(\sqrt{-i}\alpha)]\}$, using a_n as defining the coefficients of the FOURIER SERIES for the polynomial series expansion in frequency, furthermore $\alpha^2 = \text{Re} * S_r$, and R is the radius of the vessel. In this expression, the following definitions are used: Re the REYNOLDS NUMBER, S_r the Strouhal number, and J_0 the first-order Bessel function. The frequency parameters for a non-Newtonian fluid, such as the pulsatile BLOOD flow in the arteries, are determined from the Strouhal number. The Strouhal number defines the ratio of the fluidic forces due to TURBULENCE phenomena with respect to the localized internal forces specifically as a result of localized flow accelerations. The Strouhal number provides a tool to estimate the time scale for VORTEX formation. The Strouhal number is defined as $S_r = \omega D/V$, with V the average (axial) flow velocity, D is the vessel diameter, and ω the ANGULAR VELOCITY of the (dispersive/turbulent) periodic phenomenon of flow. The flow characteristics are inherently tied to the flow rate, the tube diameter, and the pulsatile frequency of the flow mechanism.

Telemetry

[biomedical, general, mechanics, meteorology] The use of WAVES for gauging DISTANCE, direction, and MAGNITUDE (i.e., velocity) as well as wind direction, primarily based on ELECTROMAGNETIC (radio)-waves, but also by mechanical means (e.g., wind direction and velocity). Also used by BATS in ACOUSTIC format. An alternative interpretation is remote sensing, next to noninvasive sensing. The determination of BLOOD flow by acoustic and LASER DOPPLER flow METROLOGY can be considered telemetry as well (see [Figure T.15](#)).



Figure T.15 The use of telemetry by means of assisted device in tracking the migration pattern of birds.

Telescope

[astrophysics/astronomy, general, nuclear, optics] Device used to increase the RESOLUTION with respect to a distant phenomenon or object. Telescopes use a broad range of the ELECTROMAGNETIC SPECTRUM, from ULTRAVIOLET to the MICROWAVE. Telescopes operating in the visible spectrum provide a means to visually enlarge an object at a great DISTANCE. Telescopes operating in other parts of the electromagnetic spectrum require SIGNAL and image-processing techniques to reveal specific characteristics of the phenomenon under observation, such as a STAR or GALAXY. Radio telescopes are used in astronomy in order to observe in the radio-frequency and microwave bands by means of an array of dish antennas. RADIO telescopes often need to rely on INTERFERENCE properties to provide location-specific information. The first use of an optical telescope was described by the scientists and spectacle makers from Germany/the Netherlands, HANS LIPPERSHEY (1570–1619; also known as Johannes Lipperhey) and ZACHARIAS JANSSEN (1580–1640) in 1608, with contributions from Jacobus Metius (1571–1624; also known as Jacobus Adriaanszoon). GALILEO GALILEI (1564–1642) built his own telescope in 1609 based on the Dutch inspiration. A brief list of notable researchers in astronomy are NICOLAUS COPERNICUS (1473–1543), Tycho Brahe (1546–1601; Tyge Ottesen Brahe, scientist from Denmark), and EDWIN POWELL HUBBLE (1889–1953). Telescopes can rely on reflective imaging or refraction imaging. Optical telescopes use both REFLECTION and refraction, often in combination, where the reflection aspect provides a larger opening ANGLE and provides smaller constraints on the material properties. Long wavelength telescopes primarily rely on reflection-based focusing (*also see HUBBLE TELESCOPE and RADIO-TELESCOPE*) (see [Figure T.16](#)).

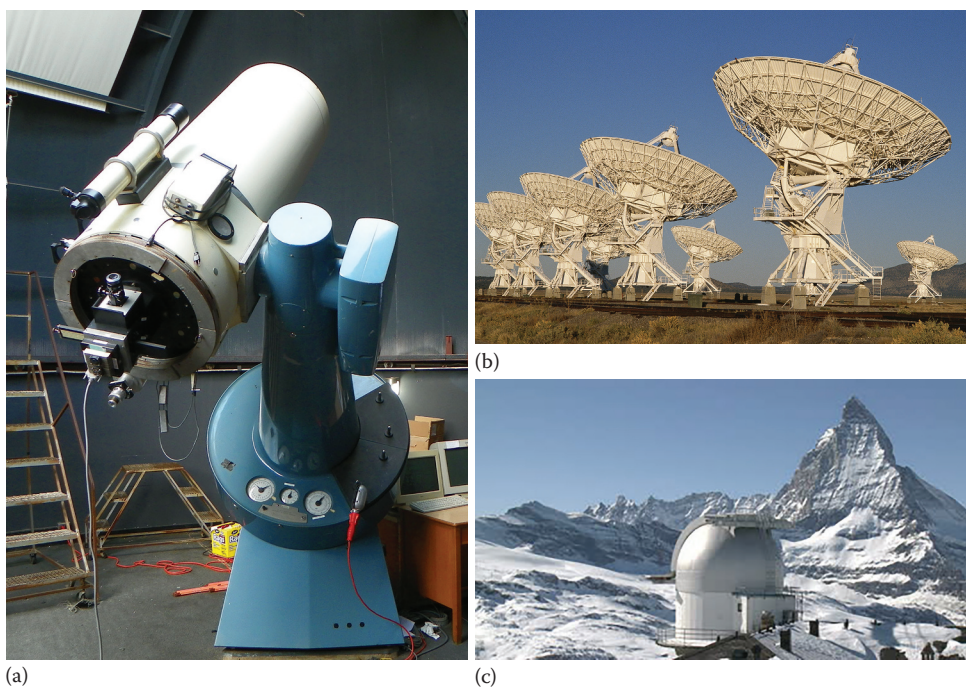


Figure T.16 (a) Picture of the telescope at North Carolina State University observatory in Durham, North Carolina; (b) image of the very large radio telescope array, consisting of 27 radioantennas, located in New Mexico; and (c) optical telescope at the base of the Matterhorn mountain in the Pennine Alps, located on the border between Italy and Switzerland.

TEM

[biomedical, imaging, nuclear, solid-state] See TRANSMISSION ELECTRON MICROSCOPE.

Temperature (T)

[general, solid-state, thermodynamics] Analogous to the definition of ABSOLUTE TEMPERATURE, temperature as a general definition may be interpreted as the aptitude for ENERGY to flow (i.e., heat) between two systems in contact, specifically from a high to low temperature (i.e., ZEROTH-LAW OF THERMODYNAMICS). Additionally temperature is the average kinetic energy of the atomic and MOLECULAR MOTION and is dependent on the atomic structure. In general, the solid-state and gaseous state can all be represented as an atomic GAS with the following characteristics: a one-atomic gas has $(3 + 0)$ degrees of freedom, a two-atomic gas has $(3 + 2)$ DEGREES OF FREEDOM, whereas the remaining multiatomic gases have $(3 + 3)$ of freedom, of which the first three are translational in a three-dimensional space (i.e., translational, vibrational, scissor action, and rotational) and the kinetic energy correlates with temperature as $(3/2)kT = KE = (1/2)mv^2 = (3/2)mv_0^2$, where k is the Boltzmann constant, m is the mass of the particles in MOTION (atoms/molecules), and v is the velocity of the motion. Temperature is expressed in either degree Celsius, degree Fahrenheit, or kelvin. The Fahrenheit scale [unit: °F] was introduced in 1717 by GABRIEL D. FAHRENHEIT (1686–1736), the CELSIUS SCALE [unit: °C, also known as the *centigrade scale*] was introduced by ANDERS CELSIUS (1701–1744) in 1742, and LORD (WILLIAM THOMPSON) KELVIN (1824–1907) introduced his temperature rendition [unit: K] in 1854. The Fahrenheit scale has 0°F defined as the MELTING POINT of water with ammonium chloride SALT (calibration point: ice and water with), a middle (third) point at the FREEZING point of distilled water at 32°F (based on the fractional distribution, i.e., powers of 2), and the upper reference the average adult HUMAN BODY temperature set at 96°F (measured with equipment and choice of MEASUREMENT, under the tongue, of the time) divisible by 12, as customary in the English unit system, with 1°F increments. Celsius uses the melting point of distilled water as the lower reference 0°C and the boiling point of distilled water as the upper calibration point at 100°C, subdivided in 100 segments. An alternative scale is the RANKINE temperature scale introduced by WILLIAM JOHN MACQUORN RANKIN (1820–1872) that follows Fahrenheit's example, but uses the ABSOLUTE ZERO defined similar to the kelvin ($T_R = (9/5)T_F$; in °R), all under standard pressure at sea level of $P = 101.325 \times 10^3 \text{ N/m}^2$. There is an easy conversion from Fahrenheit to Celsius: $T_C = (5/9)(T_F - 32)$. The Kelvin scale is similar to the Celsius scale with the elementary difference that the minimum temperature is the lowest temperature attainable (i.e., absolute zero: -273.16 K), also referred to as the *absolute temperature*. The conversion from degrees Celsius to kelvin is as follows: $T_C = T_K + 273.15$. Temperature is easily (and routinely) measured by EXPANSION, either by a change in pressure under constant volume, or by a change in volume under constant pressure (i.e., volumetric) (e.g., gas THERMOMETER; Galileo, 1592), or linear (LIQUID: e.g., water, ALCOHOL, mercury, as well as solid metals) by means of the expansion coefficient: $\Delta\ell/\ell = \alpha\Delta T$, with ℓ the length ($\sim$ column), $\Delta\ell$ the linear expansion, and α the linear expansion coefficient for the material in question. Otherwise temperature is derived from electric phenomena (bimetallic junctions changing electromotive force, V_{emf} , or conductivity as a result of the local temperature-dependent electron motion) and electronic properties (p - n junctions depending on the kinetic electron action), and finally colorimetric (i.e., change in COLOR due to temperature, alternatively used in quantifying colors). All mechanisms are assumed to operate within the linear response temperature range of the device, which imposes limitations. Since temperature is a measure of energy content, when two objects of unequal temperature are joined together the exchange of heat between the two bodies will strive for an equilibrium that has a direct correlation to the heat exchange, which in turn depends on the energy, mass, and temperature. The heat exchange will strive for equilibrium, eliminating the temperature gradient at the interface between two bodies at unequal temperatures while in contact. This defines the concept of thermal equilibrium. Combining the

temperature data with material properties such as volume characteristics yields state equations, such as the van der Waals state equation (see [Figure T.17](#)).

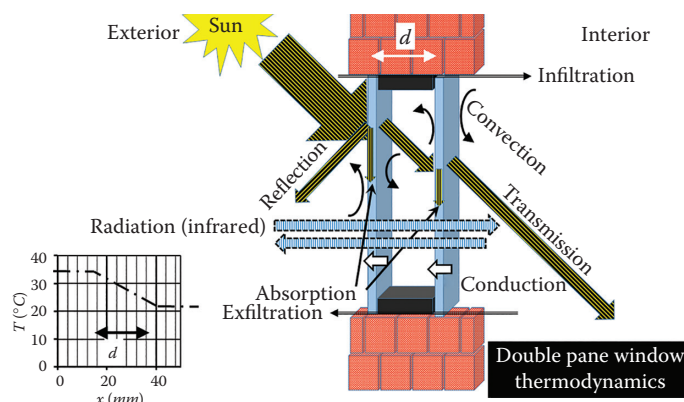


Figure T.17 Temperature gradient with respect to double glaze window, and presumed associated heat transfer.

Temporal period (T)

[acoustics, general, optics] The time frame for a harmonic event, which is directly linked to the **FREQUENCY** (ν) of the **OSCILLATION** as $T = 1/\nu$, expressed in seconds. In the electrocardiogram, for instance, the temporal period is the average time between the Q-peak for a range of QRS segments (see [Figure T.18](#)).

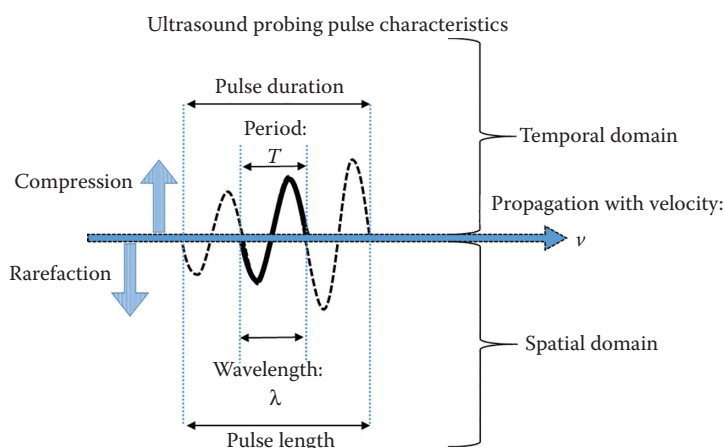


Figure T.18 Temporal period, in this diagram representing the acoustic wave in a medium.

Temporal width

[imaging, optics, quantum, ultrafast phenomena] {use: spectroscopy, hyperspectral imaging} Pulse duration of picoseconds (10^{-12} s) and shorter duration. The temporal width provides the means to measure phenomena that occur on a very short time scale, by essentially “FREEZING” the “MOTION,” as well as chemical processes of **ATOMS** and **MOLECULES**. The short temporal width allows for a detailed analysis of chemical constituents and the stages involved in the development of a chemical reaction. Ultrashort pulses inherently have a broad spectral band and are often characterized by a high **ENERGY** (i.e., irradiance) at the peak emission. Also used in coherent **X-RAY** imaging for short biological event such as intercellular **PROTON** motion. On a biomedical diagnostic level, the analysis of wound healing requires terahertz **SPECTROSCOPY**.

for an accurate classification of burn wounds, and the apropos identification of the particular physiological processes involved. Two important spectroscopic phenomena in biological functionality in the ultrashort timeframe are found in PHOTOSYNTHESIS and VISION. The LIGHT interaction in the RODS and CONES of the EYE (receptor protein: rhodopsin, CHROMOPHORE derived from vitamin A) as well as in both the SKIN and in plants with respect to the conversion of light into CHEMICAL ENERGY and oxygen production takes place on a femtosecond scale. Rhodopsin is present in both rods and cones for vision. In vision, the QUANTUM states of the excited molecules yield information on the energy transfer. The chemical processes of 11-cis retinal in rhodopsin isomerization to all-trans bathorhodopsin in a photochemical process on PHOTON absorption (energy: $h\nu$) that takes place in a 3.0 ± 0.7 ps transfer between two molecular species, approximately 1 ps into the photochemical process. One significant detectable interaction is the 11-cis to 12-cis isomerization [$C_{11} = C_{12}$ – isomerization], which reveals itself through vibrational modes in the polyene backbone (torsions); specifically the low $C_{12} - H$ VIBRATION frequency in bathorhodopsin that shows anomalous behavior. The first chemical process is associated with a transition defined by the Frank–Codon state, which has an approximate lifetime of 200 fs.

Tensile force ($\bar{F}_T$)

[general, mechanics] Force with the potential for stretching a material (*also see* TENSION).

Tensile strain

[mechanics] A rod under tension will express a normal strain, increasing in length until the ULTIMATE TENSILE STRENGTH is reached and the device will shear-off (separate) (see [Figure T.19](#)).



Figure T.19 Tensile strain.

Tensile (ultimate) strength

[engineering, general] Indication of the permissible mechanical shear stress and strain. It is of particular interest for the prediction of mechanical failure of a structure or device. The ULTIMATE TENSILE STRENGTH follows from the graphical interpretation of a plot of stress versus strain, where the stress will have an optimum, which corresponds to the ultimate TENSILE STRESS. The shear strain limit will be defined as a function of the shear strain ANGLE of distortion: $\gamma_s = \sin^{-1}(\Delta x / \ell_0) \approx \Delta x / \ell_0$, with Δx the lateral displacement

at the far end of the construction/device and ℓ_0 the characteristic length (i.e., the orthogonal DISTANCE to the origin with respect to the angle of rotation of the material strain motion). Certain biological materials can stretch at greater than 800% of the EXPANSION of most natural rubber, but not reaching the stretch for latex or nylons. The rubber balloon was introduced, almost accidentally, as the result of GAS-LAW experimentations by MICHAEL FARADAY (1791–1867) in 1824 (see [Figure T.20](#)).



Figure T.20 Tensile strength tow truck pulling car out from snowbank.

Tensile stress

[mechanics] The normal force in response to the tensile force on a cross-sectional area in a solid (e.g., rope, rod) (see [Figure T.21](#)).

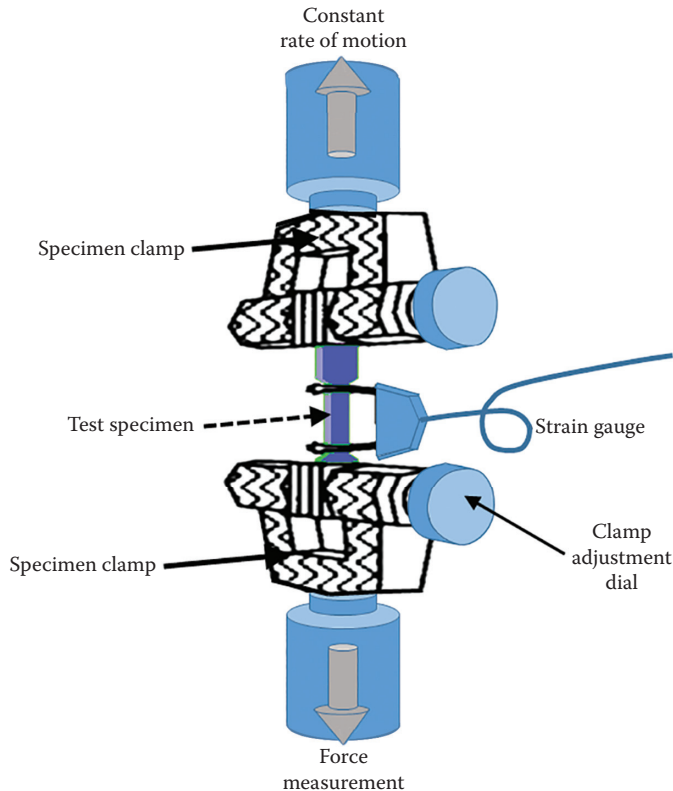


Figure T.21 Tensile stress.

Tension (F_T or τ)

[general, mechanics] SCALAR quantity of the tensile force between neighboring ELEMENTS, either in the linear direction or parallel plane. The tension in a rope will be equal in every point between the two attachment locations where an external force is applied. For a special case of surface elements (*see* SURFACE TENSION). In liquids, there is no friction and hence only normal tension will apply. In cases of lateral forces, TANGENTIAL TENSION (i.e., stress) needs to be taken in consideration (*see* Figure T.22).



Figure T.22 Tension.

Tension, surface

[hydrodynamic] *See* SURFACE TENSION. *Also see* CAPILLARITY and SURFACE ENERGY.

Tension, tangential

[mechanics] *See* STRESS.

Tensor

[atomic, fluid dynamics, solid-state] In order to place phenomena in symmetry, group theory treats the average effects, specifically applied to crystals, and respectively lattices, but also applicable to, for instance (but not limited to), FLUID DYNAMICS, general relativity, and ELASTICITY. The tensor concept introduces mathematic and geometric framework that are a generalization of vectors, matrices, and scalars. A tensor has multiple dimensions, indicated by the indices that represent the DEGREES OF FREEDOM in the applicable space. The format of the tensor as an “indexed” parameters resembles the notation of the matrix ELEMENTS, apart from the fact that the number of indices and placement of indices are arbitrary and not limited to a matrix pattern

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & a_{ij} & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix}$$

(matrix ELEMENT a_{ij}); instead tensors are found as a_{ijk} ; a_i^{jk} ; a^{ijkl} ; etc. A tensor of rank 1 is a SCALAR ($3^0 = 1$ component, e.g., temperature), tensor of rank 2 is a vector ($3^1 = 3$ components, e.g., velocity), tensor of rank 3 is a dyad ($3^2 = 9$ components, e.g., permeability, stress, flow [vortices]), tensor of rank 4 is triad ($3^3 = 27$ components, e.g., VELOCITY POTENTIAL), and so on.

Terminal velocity

[general, mechanics] The velocity of an object when all forces are balanced, resulting in a net force of zero. Under freefall, this means that GRAVITATIONAL ACCELERATION and DRAG are canceling out when a certain velocity is reached, where the ultimate velocity is a function of the elapsed time and the sum of the accelerations is a function of time. The object is in equilibrium at this point: $\sum \vec{F}_i = 0$. The terminal velocity (v_T) of a sphere with density ρ_s , traveling in a FLUID with density ρ_f can be approximated based on the Stokes STREAM FUNCTION as $v_T = (2/9)[(\rho_s - \rho_f)/\eta]gR^3$, where η is the VISCOSITY, g the acceleration, and R the radius of the spherical object. Analogously, for a cylinder in flow, the VORTICITY ($\vec{\omega} = \partial\chi/\partial\varphi$; φ the ANGLE of the velocity with the VORTEX axis) surrounding the cylinder will provide a significant influence, assuming the cylinder traveling long ways in the flow, in response to the balancing torque on the “rod.” The terminal velocity can be derived from: $v_T = [(1/2) - \gamma^* - \log((1/2)k^*R)]C$, where γ^* represents the first term in the EXPANSION: $\int_0^\infty e^{-k^*r} \cosh \vec{\omega} d\vec{\omega} = -[\gamma^* + \log((1/2)k^*r)]Y_0(k^*r) + s_1(k^{*2}r^2/2^2) + s_2(k^{*4}r^4/2^2 4^2) + s_3(k^{*6}r^6/2^2 4^2 6^2) + \dots$, where $Y_0(k^*r)$ is a zero-order Bessel function of the second kind, $k^* = |\mu|/2\eta$ an indicator of the MAGNITUDE of the viscous forces (tied to the viscous forces: $\eta\nabla^2 u$; $\eta\nabla^2 v$; and $\eta\nabla^2 w$), and C is the coefficient in the series for the vortex field solution developed in the WAKE $\chi = Ce^{k^*x} \int_0^\infty e^{-k^*r} \cosh \vec{\omega} d\vec{\omega}$, with $\vec{\omega} = \partial\chi/\partial\varphi = (3/2)\mu R(1 + k^*r)(\varphi/r^3)e^{-k^*(r-x)}$ the vorticity, and r the radius; as a SOLUTION to $\mu = -(\partial\phi/\partial x) + (1/2k^*)(\partial\chi/\partial x) - \chi$, where ϕ is the VELOCITY POTENTIAL and u the velocity in the direction of net flow (see Figure T.23).



Figure T.23 Terminal velocity without parachute.

Tesla, Nikola (1856–1943)

[general] Scientist from Croatia. Nikola Tesla dedicated his research to the electrical ACTIVITY of charges and the MAGNETIC FIELD effects. One of Tesla's major contributions to modern ENGINEERING is the alternating current electrical system, leading to the electromotor and the GENERATOR. The ac-induction MOTOR is very actively in use with modern hybrid and electric automobiles. The “Tesla coil” invented in 1891 has found many applications, such as the one in RADIO technology. The Tesla coil constitutes a high-voltage low-current high frequency electrical resonator that can go beyond the frequency range of an electrical TRANSFORMER. The Tesla coil is also used for display purposes with PLASMA arcs propagating through AIR.

Nikola Tesla designed the hydroelectric power plant in operation at Niagara Falls, New York, the United States in 1895 (see [Figure T.24](#)).

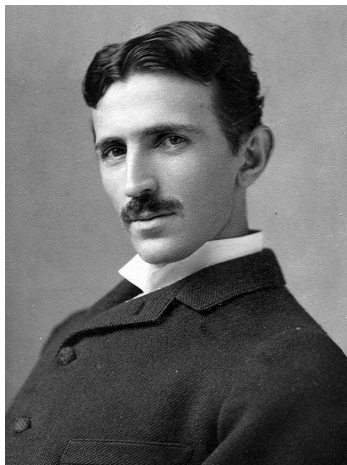


Figure T.24 Nikola Tesla (1856–1943).

Tesla (T)

[general] Unit for the MAGNITUDE of a MAGNETIC FIELD, adopted in the SI UNITS in 1960. The unit is named after a pioneer in the magnetic field theory NIKOLA TESLA (1856–1943). The unit has the following equivalents: $T = (\text{Vs}/\text{m}^2) = (\text{N}/\text{Am}) = (\text{Wb}/\text{m}^2) = (\text{kg}/\text{Cs})$. The range of magnetic field strength is broad. Examples of the magnetic field strength under various conditions are as follows: for the atomic NUCLEUS: $10^{12} T$; at the surface of a NEUTRON STAR: $10^8 T$; artificially produced under laboratory conditions: $\sim 10^3 T$; a small MAGNET: $10^{-2} T$; kitchen blender: $\sim 10^{-3} T$; the earth's magnetic field $\sim 10^{-4} T$; high voltage electric transmission lines (within close proximity): $10^{-4} T$; the HUMAN BODY: $\sim 10^{-10} T$; the smallest value in shielded environment: $10^{-14} T$.

Thales (c. 624–546 BC)

[general] Greek scientist and philosopher. Founder of the first principles of scientific method, separating divine intervention from phenomena (i.e., natural events) that have a cause that can be explained scientifically and theoretically. Some later Greek philosophers credited Thales with the first introduction of celestial navigation referring to Ursa Minor (i.e., “Little Bear”) as the point of reference. Records also mention that he proposed water as the primary ELEMENT, the source of all media (see [Figure T.25](#)).

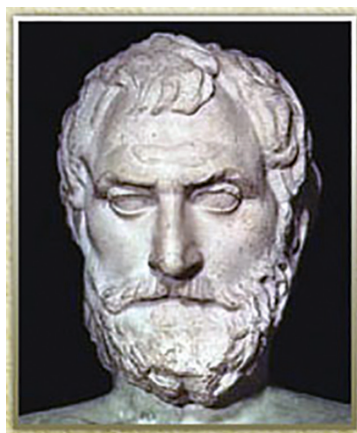


Figure T.25 Impression of how Thales (ca. 624–546 BC) may have looked like.

Theodolite

[general, geophysics] Instrument designed to provide the **ANGLE** with respect to a horizontal plane using a telescopic viewer that can pivot in vertical and horizontal directions, introduced by and used in areal construction and land surveying. The theodolite measures the azimuth angle. The concept was introduced in the 1500s and is in everyday use today (see [Figure T.26](#)).



Figure T.26 Theodolite.

Thermal conductivity

[thermodynamics] Coefficient of **HEAT TRANSFER** (heat transfer rate: $\dot{Q} = dQ/dt$) for a medium with **CROSS SECTION** A over a length ℓ and with an applied thermal gradient ($T_b - T_l$) to provide $\dot{Q} = \lambda_T [A(T_b - T_l)/\ell]$.

Thermal diffusivity ($\alpha_{\text{dif}} = \kappa/\rho c_p$)

[thermodynamics] Where κ the thermal conductivity, ρ the density, and c_p the heat capacity. Thermal **DIFFUSIVITY** describes the ability of an object to adjust to the ambient changes in temperature and the rate of change to reach equilibrium. A high thermal diffusivity means that an object adjusts rapidly, whereas a low thermal diffusivity might entail a larger **ENERGY** requirement.

Thermal energy

[general, nuclear, thermodynamics] Atomic and molecular kinetic **ENERGY**, contained as the temperature of an object. Thermal energy is part of the **CONSERVATION OF ENERGY** principle. Thermal energy may develop due to **FRICTION** or result from combustion.

Thermal equilibrium

[engineering, general, thermodynamics] Conditions for which there is no transfer of heat, all bodies with a system are at the same temperature. (*also see* **ZEROTH LAW OF THERMODYNAMICS**).

Thermal expansion

[engineering, general, nuclear, thermodynamics] Increase in **VOLUME** (V) for a system due to a change in the **TEMPERATURE** (T) of the system, generally considered under constant **PRESSURE** (P). The volume expansion is defined by the volume expansion coefficient as $\gamma_{\text{th}} = (1/V)(dV/dT)_P$. Generally the thermal expansion

coefficient is a function of temperature itself, expressed as $\gamma_{\text{th}} = a + bT + cT^2$, where a , b , and c are material constants. The EXPANSION for metallic objects is subject to both LATTICE expansion and conduction electrons, expressed by the SPECIFIC HEAT under constant pressure: $c_p = a_{\text{el}}T + a_{\text{lat}}T^3$, where a_{el} and a_{lat} are coefficients with respect to the contributions due to the electrons and the lattice. The electron and lattice expansion translates into the GRÜNEISEN EQUATION for thermal expansion: $\gamma_{\text{th}} = (1/VB_s)(\gamma_{\text{el}}a_{\text{el}}T + \gamma_{\text{lat}}a_{\text{lat}}T^3)$, where B_s is the adiabatic bulk modulus. This reduces to $\gamma_{\text{th}} = \gamma_{\text{GR}}(c_p/VB_s)$, with γ_{GR} the Grüneisen coefficient, indicating the temperature dependence for the expansion. Water is one of the few media that decreased in volume between the FREEZING point and a few degrees above freezing, with the highest density at 4°C. A large segment of metals has an almost uniform expansion coefficient around the MELTING POINT for the LIQUID phase as $\gamma_{\text{th}} \sim 10^{-4} \text{ K}^{-1}$. Under certain conditions, linear thermal expansion is required, where $\gamma_{\text{th}} = 3\alpha_{\text{th}}$; $\alpha_{\text{th}} = (1/L)(dL/dT)_p$, L the characteristic length, and α_{th} the linear expansion coefficient (see Figure T.27).



Figure T.27 Thermal expansion for a hot-air balloon, using a flame to heat up the air that will force the balloon filled with expanding air to increase in volume that will provide it buoyancy. The volume of hot air inside the balloon has a lower density and is hence lighter than the colder surrounding air providing an upward force.

T

Thermal neutrons

[atomic, nuclear] Slow moving NEUTRON, with velocities in the distribution of room temperature AIR molecules. Thermal neutrons were found very inquisitive for the examination of materials, from LIGHT to heavy metals (including uranium) during the research into the structure and ISOTOPE formation performed by ENRICO FERMI (1901–1954).

Thermal wave

[acoustic, quantum, solid-state, thermodynamics] The ability to produce CAPILLARY WAVES (at an interface) on a molecular scale by means of thermal MOTION. The thermal wave is confined by the SURFACE TENSION (σ_{surface}) and can be described as the ENERGY content ($E_{\text{SurfaceTension}}$) in the lateral displacement (height: h) along the surface (in the x - and y -directions) as $E_{\text{SurfaceTension}} = \sigma_{\text{surface}}$

$\int \{ \sqrt{1 + [(db/dx)^2 + (db/dy)^2]} - 1 \} dx dy \cong (\sigma_{\text{surface}}/2) \int [(db/dx)^2 + (db/dy)^2] dx dy$, where the displacements are of a small AMPLITUDE (also see SURFACE ACOUSTIC WAVE and CAPILLARY WAVE).

Thermionic emission

[atomic, nuclear] Release of electrons from a METAL surface under heating, generally heated through an electrical current. The process was recognized by Thomas Alva Edison (1847–1931) in 1883. The thermionic emission is used for the generation of X-RAY from the impact on a metal target (e.g., bismuth or tungsten).

Thermistor

[electronics, general] Material that has a RESISTANCE (R) that varies with applied temperature. The TEMPERATURE (T) can be derived from the CURRENT (I) under an applied VOLTAGE (V) through OHM'S LAW: $V = IR$, assuming a linear response with respect to temperature change: $\Delta R = \epsilon_{\text{const}} \Delta T$. The mechanism of action is different from a THERMOCOUPLE.

Thermoacoustic imaging

[optics, thermodynamics] See PHOTO-ACOUSTIC IMAGING and SCANNING ACOUSTIC MICROSCOPE.

Thermocouple

[electromagnetism, general, thermodynamics] Temperature sensor, generally made by joining two metals together that will provide a voltage that is a function of the temperature based on the SEEBECK EFFECT, as recognized by the German scientist Thomas Seebeck (1770–1831). One commonly used thermocouple uses two alloys: chromel (consisting of 90% nickel and 10% chromium) and alumel (consisting of 95% nickel, 2% manganese, 2% aluminum, and 1% silicon). The potential difference (V , measured at the distal end of the wire; the junction of the two metals generates a balancing current to cancel out the external potential difference) as a result of temperature (T) is defined as $V_b - V_c = \int_{T_c}^{T_b} [S_A(T) - S_B(T)] dT$, with $S_A(T)$ and $S_B(T)$ the Seebeck coefficients for materials A and B, and the subscripts c_b and c_c represent the temperature at the two junctions. The inverse process with respect to the thermocouple principles is the Peltier effect (see Figure T.28).



Figure T.28 Thermocouple used for temperature measurement.

Thermodynamics

[biomedical, chemical, engineering, mechanics, quantum, thermodynamics] Branch of engineering and physics that deals with the aspects of work, heat, temperature, and equilibrium conditions. Thermodynamics is based on the following four laws: ZEROth LAW OF THERMODYNAMICS (any two systems in contact at

the same temperature are in thermal equilibrium); **FIRST LAW OF THERMODYNAMICS** (conservation of ENERGY, INTERNAL ENERGY, and work and heat need to balance); **SECOND LAW OF THERMODYNAMICS** (heat will not flow from a cooler to warmer location without external assistance); and the **THIRD LAW OF THERMODYNAMICS** (it is impossible to reach **ABSOLUTE ZERO** temperature [in kelvin] by any process of finite number of steps). The concept of **PERPETUAL MOTION** is rejected based on at least the last two laws. Other aspects of thermodynamics include statistical **MECHANICS** and thermometry.

Thermodynamics, first law of

[energy, fluid dynamics, general, thermodynamics] The change in the **INTERNAL ENERGY** (U) of a system is the confluence of the **HEAT** (Q) introduced in the system and the work (W) done by the system on the surroundings, formulated as $\Delta U = \Delta Q - \Delta W$. The work performed can be mechanical: $W_m = P\Delta V + V\Delta P$, with P the internal pressure and V the volume of the system; or when the work is electrical: $W_e = -nF_a\Delta V_e$, with n is the number of charges transferred in the process, $F_a = 96,485$ C/mol the **FARADAY CONSTANT**, and ΔV_e is the maximum difference in electrical potential resulting from the transferred charges. This law is another version of the **CONSERVATION OF ENERGY**.

Thermodynamics, second law

[biomedical, energy, fluid dynamics, general, thermodynamics] If a system is isolated (no ENERGY is added to it) its entropy is destined to increase with time. Consider a flower that has been cut and is left in a closed container without water. The flower and stem will eventually **DECAY**, meaning that the entropy of the system has increased. Life is one of the most obvious examples where the requirement of energy input to sustain order is evident. Such processes are called **energonic**, in which the energy of the final state is higher than the energy of the initial state.

Thermodynamics, third law

[biomedical, energy, fluid dynamics, general, thermodynamics] For any mixture of constituents, known as a system, there exists one stable equilibrium that will be at zero temperature (0 K; zero degrees kelvin). The third law also states that the **ABSOLUTE ZERO** kelvin cannot be reached by any finite number of discrete steps. An equivalent statement relates to the fact that the **CARNOT ENGINE** can never have the perfect efficiency. (*also known as* **NERNST PRINCIPLE**).

Thermodynamics, zeroth law of

[general, thermodynamics] Concept introduced by **JOSEPH BLACK** (1728–1799) around 1760. The zeroth law describes the fact that every system will be endowed with the property of temperature. Placing two systems in contact will establish thermal equilibrium where both systems possess the identical temperature and no net heat will be transferred. When systems A and B are in thermal equilibrium, possessing the same physical quantity of temperature, as are systems B and C, then systems A and C are (also) in equilibrium.

Thermography

[fluid dynamics, imaging, thermodynamics] Imaging method using the **INFRARED** “signature” to identify the temperature distribution. The thermography concept is based on **PLANCK’S LAW** (accurate) or alternatively **Wien’s displacement law** (approximation). **WIEN’S DISPLACEMENT LAW** provides the peak emission wavelength (λ) as $\lambda = (2.898 \times 10^{-6}/T)$ nm, with temperature (T) in kelvin. The **PLANCK’S RADIATION LAW** gives the radiant power as a function of wavelength as $W = 2\pi hc^2/\lambda^5 (e^{hc/\lambda k_B T} - 1)$ W/m²μm. Thermography uses the spectral profile in near infrared (wavelength range $\lambda = 0.66$ – 2 μm); mid-infrared (wavelength range: $\lambda = 3$ – 5 μm); to long infrared (wavelength range: $\lambda = 7$ – 14 μm) spectrum, depending on the specific application. The two primary thermal imaging wavelength bands are $\lambda = 3$ – 5 μm and $\lambda = 8$ – 12 μm. Thermographic imaging owes its limitations to these two specific bands based on the spectral response limitations of the available photodetectors next to the transmission passband windows of the **ATMOSPHERE**; specifically within a bandwidth portion.

The monochromatic emissive power of a black-body radiation at the typical room temperatures (296 K) has an emission peak at $9.6\text{ }\mu\text{m}$. For analysis, the **EMISSIVITY** of the surface is assumed to be $\sim 96\%$ ($\epsilon_T = 0.96$; note that polished aluminum or platinum has an emissivity of only 4% , whereas water and human tissue is $\sim 96\%$, and soot 99%), but in cases otherwise known corrections can manually be entered for the surface with respect to the imaging device software processing and user interface. The modern day photodetectors use various mechanisms, ranging from photovoltaic to photodiode to photoresistive. Photovoltaic operation relies on the electron release based on the work function of the medium, generating a current that is proportional to the overall collected **PHOTON** radiance within a bandwidth. A photodiode renders a reverse bias current resulting from photoenergy exposure. The photoresistive **ELEMENT** changes its charge-carrier density under the influence of photon **ENERGY**; this type of device is semiconductor based. Typical photoresistive **ELEMENTS** designed for the $\lambda = 8 - 12\text{ }\mu\text{m}$ band are MCT ($\text{Hg}_{0.8}\text{Cd}_{0.2}\text{Te}$) detectors, one of the few molecular structures that has a small enough bandgap with the **VALENCE BAND**. The detectors can be actively balanced in a Wheatstone configuration to minimize the conductive heating aspects, which will influence the sensitivity and accuracy. Generally a CCD imaging device uses MOSFET photodiodes that operate based on charge depletion under exposure. Each **PIXEL** is its own MOSFET element. Thermographic cameras are constructed with an array of infrared sensitive elements (pixels) that is processed for **MAGNITUDE** with a certain spectral band to provide the spatial distribution of surface temperatures. Virtually all thermographic-sensing devices require cooling, primarily designed to reduce the thermal noise as well as to increase the dynamic range. The cooling processes can be either by means of **LIQUID** nitrogen (temperature 77.4 K , -196°C) or through Peltier elements (thermopile), next to Joule–Thompson cooling devices (relying on isentropic **EXPANSION** of a pressurized **GAS**, similar to household refrigeration). Because of the fact that infrared **RADIATION** is readily attenuated by any material except for **AIR** and **VACUUM**, only the external surface of an object is analyzed for temperature. Any coating, plastic **BARRIER**, or wax/**OIL** covering will change the spectral profile of the **LIGHT** emitted from the **BLACK BODY**, hence altering the perceived temperature. Thermal imaging is subject to a variety of **NOISE** sources, ranging from thermal noise to shot noise (intrinsic semiconductor defect) and the random generation of charge carriers/holes (G–R noise; generation–recombination noise), which is not thermally activated, and has a spectral profile. Night-vision instrumentation also provides a form of thermographic imaging since it applies to near infrared, only slightly above the **RED** vision cut-off. Infrared imaging dates back to 1929, starting with night **VISION**, designed by the Hungarian scientist Kálmán Tihanyi (1897–1947). The next developmental **PHASE** was a spectral line scanner, which reconstructed images from obtaining emissions from points on parallel lines traced out on the surface of the object as designed by Texas Instruments in 1947, requiring up to an hour exposure. The last major breakthrough prior to the current state-of-the-art instrumentation was through pyroelectric scanning integrated with a full surface view developed by Michael Francis Tompsett (1939–) in 1969, later on perfected with solid-state sensor technology (CCD). (see **BLACK-BODY RADIATION**) (see Figure T.29).

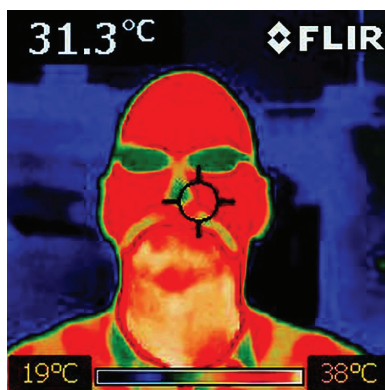


Figure T.29 False-color image captured by thermography camera displaying temperature distribution of an object based on the Planck radiation profile, by means of collection of infrared radiation. Most thermographic cameras operate in the wavelength band of $3 - 5\text{ }\mu\text{m}$, other detection bands are available, including but not limited to, $1 - 2\text{ }\mu\text{m}$ and $8 - 12\text{ }\mu\text{m}$.

Thermokinetic oscillator

[chemical, energy, thermodynamics] *See* OSCILLATORY REACTION.

Thermometer

[energy, fluid dynamics, general, geophysics, thermodynamics] Device designed to quantify local temperature. The mechanism of action for the determination of the temperature can be THERMOCOUPLE based, thermo-electric (semiconductor), or linear EXPANSION of a FLUID in a confined tube under vacuum. The most well-known thermometers are the mercury and ALCOHOL liquid thermometers and the thermocouple-based probe, next to the thermographic (INFRARED sensitive) semiconductor sensor used for in-ear thermometry (see Figure T.30).

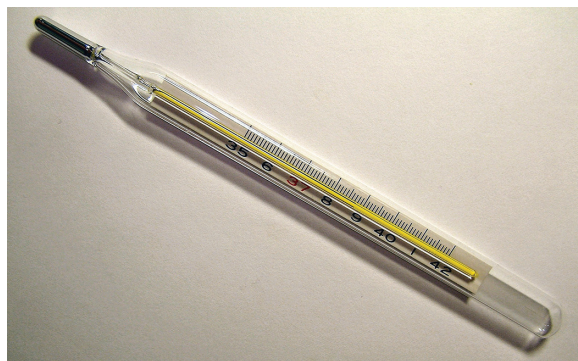


Figure T.30 Illustration of the use of a thermometer to measure body temperature and establish whether the person has a fever.

Thermonuclear energy

[atomic, general] ENERGY released from NUCLEAR FUSION or NUCLEAR FISSION processes (*see* THERMONUCLEAR FISSION *and* THERMONUCLEAR FUSION).

Thermonuclear fission

[atomic, general] Most nuclear power plants operate on induced fission of uranium-235, under prodding from colliding neutron (η). In this process, the NEUTRON briefly merges with the uranium to subsequently disintegrate in barium-138, krypton-95, and three new neutrons. This process results in the release of ENERGY that is based on the energy transfer for the nuclear binding forces in the molecular balance:

$${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U}^* \rightarrow {}_{56}^{141}\text{Ba} + {}_{36}^{92}\text{Kr} + 3{}_0^1\text{n} + 220\text{ MeV},$$
 where some energy is applied to the recombination (~ 20 MeV). The neutrons released in the FISSION process can continue to fuel the fission process. The effective 200 MeV fission energy almost all goes into THERMAL ENERGY (at least a verified 165 MeV as kinetic energy, whereas an additional 10 MeV out of all 200 MeV is released as kinetic energy, not as the anticipated neutrinos; 7 MeV as kinetic BETA PARTICLES [totaling 182 MeV in kinetic energy, producing thermal effects: $\text{KE} = (3/2)k_B T$]; next to 5 MeV as kinetic neutrons [used for fission] and the remaining theoretical

distribution is 7 MeV + 6 MeV to gamma RADIATION; primary and secondary) (see NUCLEAR FISSION and FISSION) (see Figure T.31).

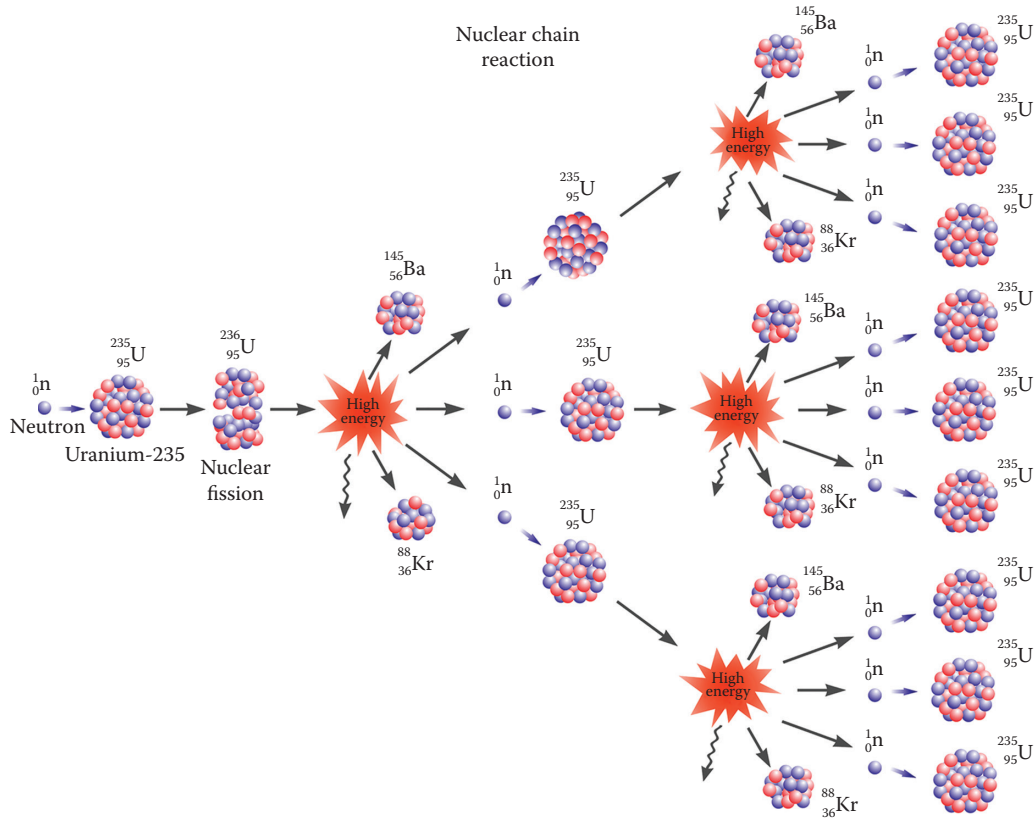


Figure T.31 Nuclear chain reaction for uranium fission.

Thermonuclear fusion

[atomic, general] Most galactic stars operate on the process of NUCLEAR FUSION, joining two light nuclei (e.g., hydrogen (H)/proton (${}^1_0\text{n}$)) into larger/heavier nuclei: ${}^1_0\text{n} + {}^1_0\text{n} \rightarrow {}^2_0\text{H} + e^+ + \nu + 0.42 \text{ MeV}$, e^+ a positron that will annihilate a free electron and release an additional 1.02 MeV of ENERGY and ν a NEUTRINO. The gain in energy is provided based on the fact that the BINDING ENERGY is different for a set number of nuclides based on the ATOM number. Protons can be brought in close contact to the point where they will overcome their Coulomb repulsion. The KINETIC ENERGY (KE) to achieve proximity will need to exceed the center-to-center potential energy PE (Coulomb energy) of approximately 0.14 MeV, for separation of $r = 10^{-14} \text{ m}$ for the respective protons. This energy level equates to an approximate temperature of $T = 1 \times 10^9 \text{ K}$ ($KE = (3/2)k_bT$, $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ Boltzmann constant). In practicality, the effective fusion temperature is 50 times lower (only at 2% of the thermal equilibrium) due to the fact that there will be an energy distribution around the calculated maximum energy, next to TUNNELING events. Fusion can be used to generate power on an artificial basis; however, most nuclear power plants are fission plants. The FUSION

plants in experimental use operate on tokamak (MAGNETIC) principles or laser INERTIA confined plasmas (see NUCLEAR FUSION and FUSION) (see Figure T.32).

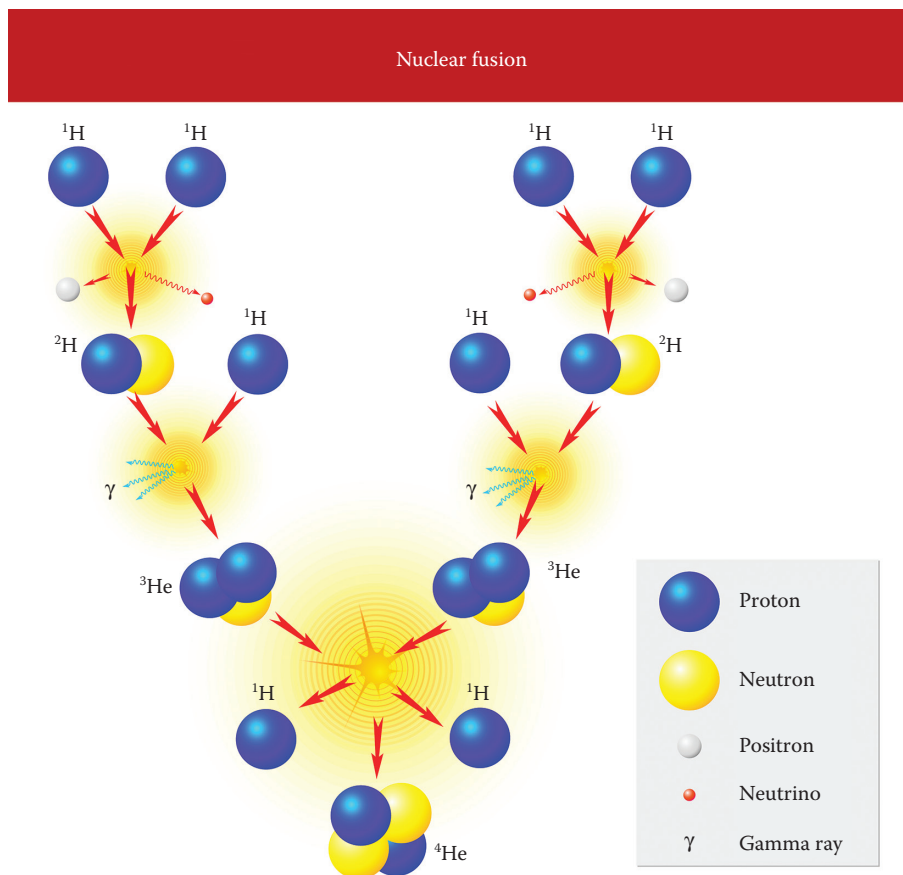


Figure T.32 Diagram of nuclear fusion and energy balance.

Thermophysical properties

[thermodynamics] Theoretical and experimental parameters associated with a single constituent system in one-phase, two-phase, or three-phase states. The system consists of n molecules in a volume V , specific volume: $v_V = V/n$ with internal ENERGY (U), specific internal energy: $u_U = U/n$, entropy (S), and respectively specific entropy: $s_S = S/n$ and has a TEMPERATURE (T), PRESSURE (P) and DENSITY ($\rho = m/V$, for a PHASE with mass m of a chemical with MOLECULAR WEIGHT M). The amounts of constituents can be expressed in MOLE or mol (i.e., GRAM MOLE). With respect to phase transitions, the following specific thermophysical properties apply. The critical pressure (P_c), at which the LIQUID and VAPOR phase are treated as identical. The CRITICAL TEMPERATURE (T_c), at which the vaporization process reduces to an infinitesimal event. And an additional critical specific volume is also identified: v_{Vc} . Combining the three conditions of critical pressure, critical temperature, and critical specific volume yields the critical state or critical point. Particular to the form of AGGREGATION at the phase changes, there are specific LATENT HEAT values that define the energy requirements to accommodate the PHASE TRANSITION from one phase to the other. For a two-phase mixture, the chemical potential μ_i defines the phase MIXING under the CLAUSIUS–CLAPEYRON RELATION. Next to the specific latent heat at the phase transitions, there is also the specific heat under constant pressure (c_p) and SPECIFIC HEAT under constant volume (c_v) that both define the heat requirements per degree of temperature rise per unit mass. The equation of state provides a

means to interconnect a range of thermophysical properties and predict the course of events. Furthermore during EXPANSION and compression, the thermophysical properties of isothermal compressibility (K_T) and isobaric expansion (α_p) are important for the description of a process, plus they tie into the equations of state. The final thermophysical property on the list is the speed of SOUND for the medium under particular values of the aforementioned thermophysical properties. The speed of sound (v_s), as all the other thermophysical properties, can be measured and is correlated to some of the other properties through $v_s^2 = (\partial P / \partial \rho)_{ss} = -(v_V / M)(\partial P / \partial v_V)_{ss} = -(v_V / M)\{ (c_p / c_v)(1 / K_T v_V) \} = (c_p / c_v)(1 / \rho K_T) = \gamma_r (1 / \rho K_T)$, where γ_r is the ratio of the specific heats.

Thermoscope

[general, thermodynamics] THERMOMETER equivalent designed by GALILEO GALILEI (1564–1642), however, without a scale, introduced in 1617. A bowl partially filled with LIQUID has a tube leading upward where the rising liquid can spill into a bulb. The GAS pressure in the partially filled bowl will exert pressure on the fluid surface, pushing the liquid up through the tube, where the fill fraction of the bulb will be an indirect function of the temperature. The first practical temperature scale was introduced by OLAUS ROEMER (RØMER) (1644–1710) in 1701; followed shortly by GABRIEL DANIEL FAHRENHEIT (1686–1736) in 1717. Without much consequence at the time, a physician from France, Jean Rey (1583–1645) turned the Galilei thermoscope upside down and filled the bulb with water and started using it for measuring body temperature as a relative value in 1631, a definite preamble to the modern thermometer (see [Figure T.33](#)).

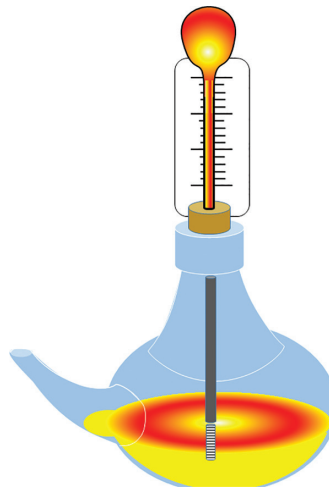


Figure T.33 Thermoscope.

Thermosphere

[energy, geophysics, thermodynamics] Shell of the Earth's ATMOSPHERE, the layer with the greatest thickness; spanning from 85 to 500 km. The thermosphere is located above the MESOSPHERE and has the EXOSPHERE on the outside. Within this layer, gaseous molecules and atoms are ionized under the exposure of the sun's short ULTRAVIOLET RADIATION. This ionization is what is observed as the auroras: AURORA BOREALIS and AURORA AUSTRALIS. The IONIZATION layer also provides a "reflective" layer for RADIO communications. Especially long-wave electromagnetic radiation can reflect off the ionized layers in the atmosphere and back from the earth's surface and allow long-wave radio waves to travel half-way around the EARTH (e.g., ham radio transmissions from Australia can be received in the United States, depending on atmospheric conditions). The temperature in the thermosphere increases with altitude as a result of the solar interaction. The thermosphere has a dynamic character, including atmospheric tides, a THERMAL WAVE pattern driven by DIURNAL heating. The atmospheric tides form a global OSCILLATION in the atmosphere. Atmospheric tides

are also common in the TROPOSPHERE and the STRATOSPHERE, based on the solar absorption in the high concentration of water VAPOR and ionization of oxygen to ozone. Based on the solar interactions, the tides have a period on the order of 12 and 24 h intervals; however, the periods become longer with greater altitudes. The flow direction of the tides is also subject to the orientation of the earth's axis with respect to the orbit around the SUN (seasonal fluctuations). The atmospheric tides are affected by gravitational influences next to the solar heating, and hence are also dependent on the lunar orbit. Atmospheric tides are considered as linear perturbations and are eigenvalues of the Hough functions. The Hough functions are special cases of the Laplace tidal equations. The LAPLACE EQUATION for the tidal WAVE of the atmospheric flow uses the Hough EIGENFUNCTION ($\Theta_n(\varphi_e)$) and Hough eigenvalues ($\zeta_n = (2\omega_e R_e)^2 / g(r, \varphi) r_n$, where $g(r, \varphi)$ is the GRAVITATIONAL ACCELERATION as a function of global atmospheric location) and is written as $L\Theta_n(\varphi_e) + \zeta_n \Theta_n(\varphi_e) = 0$, with the Laplace tidal operator $L = (\partial/\partial\Phi^*) \{ [(1 - \Phi^{*2}) / (Z^2 - \Phi^{*2})] (\partial/\partial\Phi^*) \} - [1 / (Z^2 - \Phi^{*2})] \{ (\kappa_z / Z) [(Z^2 + \Phi^{*2}) / (Z^2 - \Phi^{*2})] [\kappa_z^2 / (1 - \Phi^{*2})] \}$, introducing $\Phi^* = \sin \varphi_e$ and $Z = v_e / 2\omega_e$. The solutions are placed in the reference frame longitudinal (θ_e) and latitude location (φ_e), with the angular velocity of Earth (ω_e), the atmospheric density ($\rho \propto e^{-r/H}$, r the altitude, H_a the “thickness” of the atmosphere), and $\kappa_z = 2\pi/\lambda_z$ the zonal wavenumber, λ_z is the zonal wavelength, v_e zonal frequency, r the altitude, and R_e is the radius of Earth. The general solutions to the Laplace equation are the Lamb waves in the Bessel function of a decaying order (lower impact for higher order BESSEL FUNCTIONS) as well as other propagating damped wavefunctions (*also see* **HOUGH EQUATION, LAMB WAVES, and BRUNT-VÄISÄLÄ BUOYANCY FREQUENCY OF THE ATMOSPHERE**) (see Figure T.34).

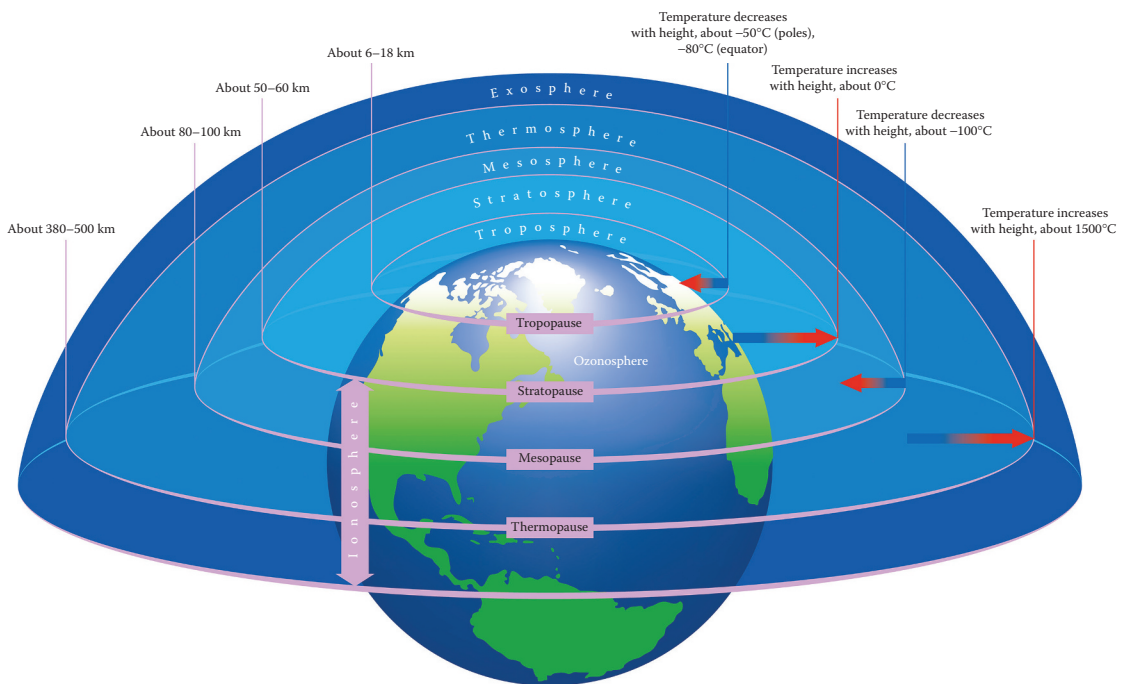


Figure T.34 Earth's thermosphere.

Thermostatistics

[thermodynamics] Classical THERMODYNAMICS defining equilibrium states. Also known as “highest-entropy” PHYSICS.

Thévenin, Léon Charles (1857–1926)

[electronics] Electrical engineer from France. The circuit theory EQUIVALENCE PRINCIPLE as derived by Léon Thévenin in 1883 was apparently independently derived by HERMANN VON HELMHOLTZ (1821–1894) in 1853. The Thévenin theorem is cited more frequently than the Helmholtz theorem (see [Figure T.35](#)).



Figure T.35 Léon Charles Thévenin (1857–1926).

Thévenin's theorem

[electronics] The combination of several supplies with independent EMF (electromotive force; electrical potential) and any combination of circuit ELEMENTS all between two terminal poles is equivalent to a single EMF in series with a single equivalent impedance between the same two poles. The Thévenin's theorem was described by LÉON CHARLES THÉVENIN (1857–1926). The value of the equivalent EMF source is the potential difference measured between the two terminals when the current is zero and the equivalent impedance is the same as the impedance measured when the equivalent EMF is zero (*also see* **KIRCHHOFF'S LAW**) (see [Figure T.36](#)).

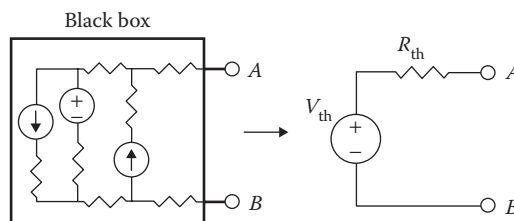


Figure T.36 Thévenin's theorem.

Thick lens

[optics] Lens with a separation between the two surfaces on the optical axis that can result in the formation of an IMAGE within the LENS material. The ray shaping is described by the LENS MAKER'S EQUATION (see [Figure T.37](#)).

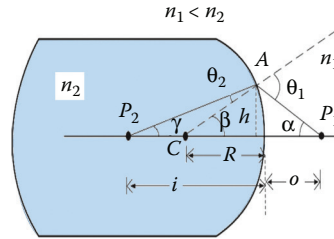


Figure T.37 Thick lens configuration and derivation of lens equation.

Thin lenses, combinations of

[general, optics] In practice, this describes an optical device that does not form an IMAGE inside the transparent object. The thin-lens equation describes the formation of an image at DISTANCE “ i ” from the LENS with respect to the object at DISTANCE “ o ” with respect to the radius of curvature of the incident surface (R_1) and the emerging surface (R_2), both taken with respect to the center of the lens with index of refraction n_2 as $(1/i) + (1/o) = [(n_2 - n_1)/n_1][(1/R_1) - (1/R_2)] = (1/f) = P$, where f represents the focal length of the lens, n_1 the index of refraction for the medium outside the lens, and P the power of the lens in diopters. A concave lens surface will result in a negative radius of curvature for that surface (*also see LENS EQUATION and THICK LENS*). Combinations of thin lenses will have a focal length that is the reciprocal sum of the individual focal lengths: $(1/f_{\text{tot}}) = +(1/f_1) + (1/f_2) + \dots$ (see [Figure T.38](#)).

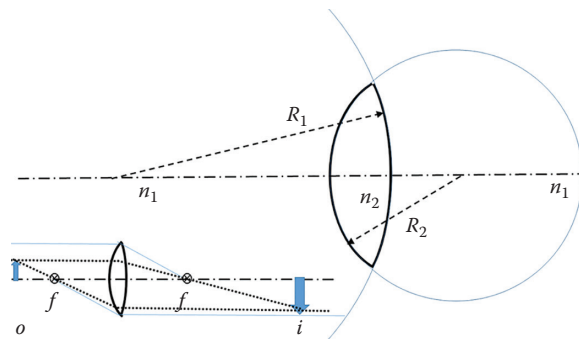


Figure T.38 Thin lens configuration and image formation.

Third law of thermodynamics

[thermodynamics] See THERMODYNAMICS, THIRD LAW.

Thixotropic liquid

[fluid dynamics] Fluid with a decreasing APPARENT VISCOSITY as a function of time while under a constant shear rate.

Thomas precession

[atomic, relativistic] Correction factor to the ENERGY shift in the spectral FINE STRUCTURE (primarily for the HYDROGEN ATOM) related to the ORBITAL ANGULAR MOMENTUM, with magnitude $\frac{1}{2}$ (named after Llewellyn Hilleth Thomas [1903–1992] based on his 1926 publication) with respect to the influence of a MAGNETIC FIELD ($\vec{B}$) on the MAGNETIC MOMENT ($\vec{\mu}_{\text{mag}}$) expressed by $\Delta E = -\vec{\mu}_{\text{mag}} \cdot \vec{B} = (Ze^2\hbar^2/8\pi\epsilon_0c^2m_e^2)r^{-3}$, where r^{-3} is the expectation for the location r , which can be considered the BOHR RADIUS (n^2a_0) under nonrelativistic conditions, $e = 1.60217657 \times 10^{-19}$ C the electron charge, Z the PROTON number (atomic number), $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34}$ m²kg/s the PLANCK'S CONSTANT, c the speed of LIGHT, m_e the electron mass, and $\epsilon_0 = 8.85419 \times 10^{-12}$ C²/Nm² the permittivity of free space. The correction is based on the fact that a horizontal spin axis (e.g., top with “circumference” equivalence for atom) will be thrown off balance when a mass is added on one side of the ring. The process can take place during the L - S COUPLING (orbital angular momentum coupled to SPIN momentum; referred to as the relativistic spin–orbit effect), providing a torque on an electron that has its spin “flipped.” The applied torque will provide a PRECESSION analog to the LARMOR PRECESSION.

Thompson, Benjamin, Sir (1753–1814)

[general, thermodynamics] COUNT RUMFORD. Physicist from the United States. Ben Thompson had a passion for explosives and gunpowder, which led him to work on thermodynamic concepts, experimentally deriving the SPECIFIC HEAT for several substances. His efforts also applied to the THERMAL CONDUCTIVITY of gasses, or better, indicating the lack thereof (see [Figure T.39](#)).



Figure T.39 Sir Benjamin Thompson (1753–1814). Painting by Thomas Gainsborough 1783.

Thomson, George Paget, Sir (1892–1975)

[atomic, general, nuclear] Physicist and Nobel Laureate from Great Britain. George Thomson and CLINTON JOSEPH DAVISSON (1881–1958) shared Nobel Prize for their verification of the DE BROGLIE WAVELENGTH during electron–electron diffraction (see [Figure T.40](#)).



Figure T.40 Sir George Paget Thomson (1892–1975). (Courtesy of Nobel Foundation, Stockholm, Sweden.)

Thomson, Joseph John (1856–1940)

[atomic, energy, general, nuclear, quantum] Physicist from Great Britain. J.J. Thomson constructed a VACUUM tube to investigate the nature of CATHODE RAYS, and this resulted in the discovery of the electron in 1897, also based on the findings by his colleague, the French scientist, JEAN BAPTISTE PERRIN (1870–1942). The electron was the first verified subatomic PARTICLE. Thomson also invented the MASS SPECTROMETER. Thomson experimentally showed the deflection of a charged particle with charge e , smaller than an ATOM, moving with velocity v with mass m_e under the influence of an external electric field ($\vec{E}$) applied by two charged plates with length L , along with a MAGNETIC FIELD ($\vec{B}$) applied parallel to the orientation of the plates. The deviation in DISTANCE from the central axis and the axis of incidence is expressed as $e/m_e = 2y\vec{E}/L^2\vec{B}^2$, due to the large deflection the mass of the charged particle had to be less than the known mass of the hydrogen ion (H^+), by a factor 1836, and hence the mass had to be equally smaller and was thus recognized as the first subatomic particle, later identified as the electron. In 1899, Thomson further detailed his discovery with the PHOTOELECTRIC EFFECT. The work by Thomson inspired the charge qualification set up by ROBERT ANDREWS MILLIKAN (1868–1953) with the “oil-drop” experiment. Robert Millikan also further refined the photoelectric effect and defined it mathematically in 1914–1915. J.J. Thomson dedicated a great deal of his time on the essential characteristics of the cathode ray and

discovered that the ray was not equivalent to electromagnetic RADIATION with a much slower propagation velocity in 1894 (see [Figure T.41](#)).



Figure T.41 Joseph John Thomson (1856–1940).

Thomson, William (1824–1907)

[general, thermodynamics] Scientist from Scotland, Great Britain. Generally referred to as Lord Kelvin (see **KELVIN** [**LORD KELVIN**; **1ST BARON KELVIN**]).

Thomson atom

[atomic, general] Even though **JOSEPH JOHN THOMSON** (1856–1940) revealed the existence of the electron, there was ample prior work indicating a charge distribution in the **ATOM**. The electronic force description by **CHARLES-AUGUSTIN DE COULOMB** (1736–1806) was inconclusive, and the follow-up remarks by the mathematician from Great Britain, **SAMUEL EARNSHAW** (1805–1888) in 1831 [**EARNSHAW'S THEOREM**], stating that an inverse square law does not create an equilibrium condition unless the charges are in **MOTION**, led to the atomic model produced by J.J. Thomson in 1903. Additional contributions by **JEAN BAPTISTE PERRIN** (1870–1942) in 1901 and **LORD KELVIN** (1824–1907; **WILLIAM THOMSON**) in 1902 provided the building blocks of the “**RAISIN-PUDDING ATOM**” published in 1903. The incorporation of the full impact of Earnshaw's statement by **ERNEST RUTHERFORD** (1871–1937), eighty years later, did not happen until

1911 when the atomic model with a NUCLEUS surrounded by electrons in ORBITS like planets around the SUN was adopted. The Rutherford “planetary” model still provides the best description for all relativistic and nonrelativistic atomic phenomena (see [Figure T.42](#)).



Figure T.42 Thomson atom model.

Thomson scattering

[atomic, nuclear] SCATTERING of the CATHODE ray “particles” that interacted with the “AETHER,” dissociating the cathode ray from electromagnetic RADIATION as investigated by JOSEPH JOHN THOMSON (1856–1940) in the period 1895–1897 (see [Figure T.43](#)).

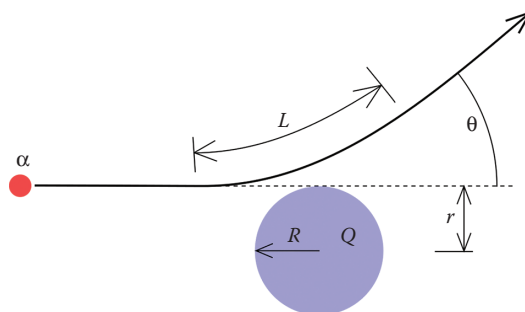


Figure T.43 Thomson scattering.

Thorium radioactive series

[atomic, nuclear] Thorium DECAY is used to identify one of three kinds of decay, next to radium or uranium decay, and the ACTINIUM decay families. The family indication represents the fact that the end product of these three series of decay is a different stable ISOTOPE of lead. Thorium-232 is abundantly available in

nature, and itself produces radon, a radioactive GAS found in the basement of many houses (*see* DECAY CHAIN) (*see* Figure T.44).

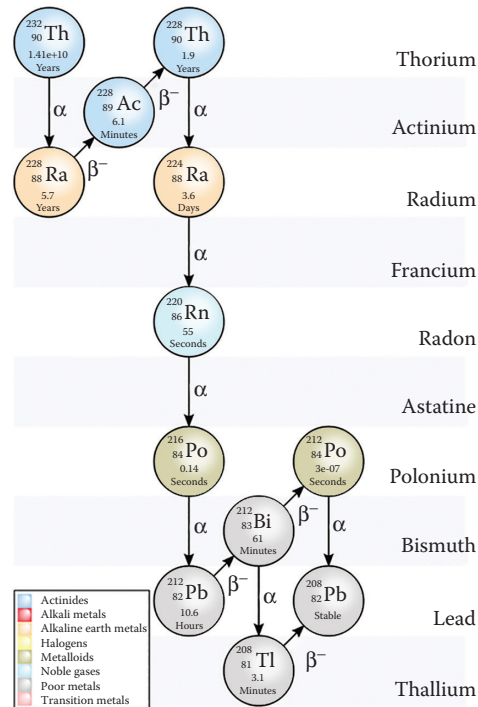


Figure T.44 Thorium.

Thorndike, Edward M. (1906?–)

[general] Physicist from the United States, who in 1932 in collaboration with Roy J. Kennedy, experimentally refuted the AETHER–wind contraction theorem postulated by ALBERT EINSTEIN (1879–1955). Their means of experimentation involved a modified Michelson–Morley INTERFEROMETER and confirm the special relativity aspects of the phenomenon.

Three Laws of planetary motion

[astro, general] Laws introduced by JOHANNES KEPLER (1571–1630) based on the experimentally derived data from TYCHO BRAHE (1546–1601). The first law states that planets move in elliptical ORBITS around the SUN, not in circular orbits as generally assumed (in practice the ellipse is not far from a circle, but the mechanical impact is crucial). The SECOND LAW states that the orbit around the Sun for each PLANET within incremental equal time frames demarcates equal areas, though with different chord lengths or arcs.

T

The diagram illustrates an elliptical orbit with the Sun at one focus. Earth is shown at two positions: perihelion (left) and aphelion (right). The semi-major axis is labeled a , the distance from the Sun to Earth at perihelion is R_p , and at aphelion is R_a . The distance from the Sun to the opposite focus is ea . The diagram also shows the Sun-Earth ratio "not" to scale.

Labels in the diagram include:

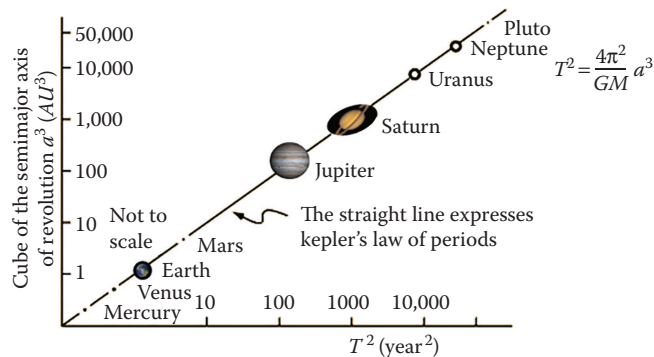
- $R_a = a(1 + e)$
- $R_p = a(1 - e)$
- Sun-Earth ratio "not" to scale
- Aphelion
- Opposite focus of ellipse
- e : Eccentricity of ellipse
- a : Semi major axis of ellipse
- Perihelion

- (a) All planets move in elliptical orbits, with the Sun at one focus

[illegible]

- (b)

Square of orbital period: $T^2 = \frac{4\pi^2}{GM} a^3$; a the planetary orbital radius (average)



- (c) The third law is derived from the law of gravitation. Sir Isaac Newton
Kepler's third law to base his law of gravitation on.

Figure T.45 Kepler's laws of planetary motion (a) first law, (b) second law, and (c) third law.

Throttle

[fluid dynamics, thermodynamics] PIPE segment with initial sharp decrease in CROSS SECTION in the direction of flow leading up to an ORIFICE, followed by a discontinuous increase to the original cross-sectional area. The function of the throttle is to introduce TURBULENCE at the discontinuity and facilitate a pressure drop. The general purpose of the throttle is to control the pressure drop between the inlet and output of a pipe segment. In certain cases, the orifice is adjustable in cross section, in which case it is called a throttle VALVE. The throttle valve has for instance been used in carburetor-controlled engines to regulate the flow of gasoline and hence control the revolutions of an INTERNAL COMBUSTION ENGINE and thus influence the velocity of movement for the automobile (*also see VENTURI*) (see [Figure T.46](#)).

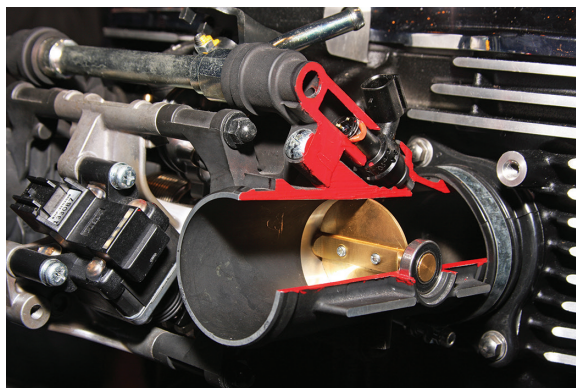


Figure T.46 Throttle.

Thrust

[fluid dynamics] Push force. The push force can result from a jet ENGINE or a PROPELLER. The thrust force from a propeller can be defined as $F_T = (\pi/4)D^2\rho\Delta U[U + (\Delta U/2)]$, with D the propeller diameter, U the incoming flow velocity, and ΔU the increase in flow velocity due to the propeller action, assuming constant and equal pressure before and after the propeller. This principle applies in approximation both to airplane and boat PROPULSION. Alternatively, the thrust from a jet engine is defined by the impulse resulting from the combustion, measured by the ejected quantity of molecules resulting from the JET explosion, in which the bulk mass of molecules (m) is expelled at a high time averaged velocity over the diameter of the jet engine while the plane is in MOTION ($\vec{v}$), providing a momentum $\vec{p} = m\vec{v}$. The impulse force is now $\Sigma F = dp/dt = m(\partial\vec{v}/\partial t) + \vec{u}(\partial m/\partial t)$, note that mass is expelled and the mass rate of ejection is linked to the DENSITY (ρ) as $dm/dt = \rho Av$, where A is the CROSS SECTION of the output flow; $\vec{u}$ is the flow velocity with respect to the reference frame of the plane. Hence the thrust is provided by the expelled exhaust

$\vec{F}_T = \vec{u} \left(\partial m / \partial t \right)$. Note that the same principle applies to opening a fire extinguisher while sitting on a chair (see [Figure T.47](#)).



Figure T.47 Thrust.

Thyatron

[atomic, electronics, nuclear] ELECTRON TUBE design that applies a grid structure to the gas DIODE rectifier. The introduction of the GAS (e.g., argon, mercury vapor, or xenon) reduces the voltage BARRIER, hence increasing the efficacy as a RECTIFIER. Applying a variable potential (ranging from negative to positive) as positioned between the CATHODE and the ANODE regulates the electron and ION flow across the tube. The grid may also provide a means of deionization for the gas, with time frames ranging from 10 to 1000 μ s, the shortest time with hydrogen as the facilitating gas. In the 1960s, the thyatron has been replaced by the THYRISTOR. The thyatron cannot provide amplification.

Thyristor

[electronics] SOLID-STATE (semiconductor) switch. Some thyristors have photosensitive characteristics.

Tidal breathing

[biomedical, fluid dynamics] The periodic and repetitive inhalation and exhalation of GAS in and out of the lungs respectively under stable boundary conditions, no exercise and under normal pressure and oxygen SATURATION. Some of the parameters associated with tidal breathing and derived parameters are expiratory reserve volume, functional residual capacity, INSPIRATORY CAPACITY, INSPIRATORY RESERVE VOLUME,

RESIDUAL VOLUME, TIDAL VOLUME, total lung capacity, and vital capacity. All the breathing parameters can be determined by spirometry (see RESPIRATION) (see Figure T.48).

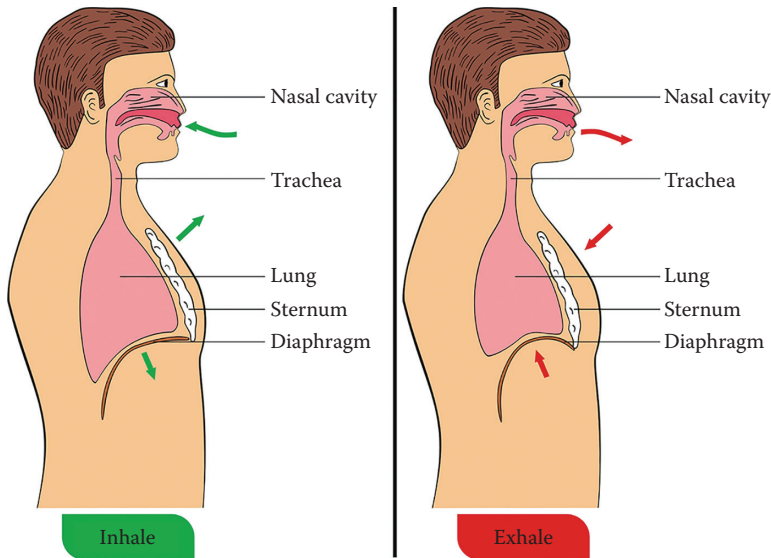


Figure T.48 Tidal breathing as an integral aspect of the respiration.

Tidal forces

[general, geophysics, mechanics] Forces that influence the DYNAMICS of the earth's surface water. Atmospheric flow, as well as EARTH'S CRUST, is primarily the result of gravitational attraction from the MOON and the SUN. The gravitational force is a function of the DISTANCE (r) between two or more bodies of mass (m_i), which can be LIQUID segments, expressed as $\vec{F}_g = G(m_1 m_2 / r^2) \vec{e}_r$, where $\vec{e}_r$ represents a unit vector in the direction of the connecting line between the two mass segments, and $= 6.67259 \times 10^{-11} \text{ Nm}^2 / \text{kg}^2$ the gravitational constant. Taking one of the masses as a solid distant object (M) influencing the attraction on a volume of liquid on EARTH will create an incremental drop in GRAVITATIONAL ACCELERATION ($\vec{a}_g$) with increasing distance (Δr) on the curvature of the face of the PLANET, expressed by the Maclaurin series as $\vec{a}_g = -G(M/r^2) \vec{e}_r \pm 2G(M/r^2)(\Delta r/r) \vec{e}_r \mp 3G(M/r^2)(\Delta r/r)^2 \vec{e}_r \pm \dots \mp \dots$. The gravitational force exerted by the moon's angular momentum on the earth's crust is gradually slowing down the earth's rotation, at a rate of $2.5 \times 10^{-9} \text{ s/day}$. The tidal force is providing a nonuniform force on a large body, specifically when the body is free to move with respect to its "host." Since GRAVITY obeys the inverse square law, the attraction will be greatest at the closest proximity on a curved surface facing another object. The gravitational tides on the earth's crust add to the centripetal forces of rotation to provide an elongation of the sphere, converting it into an ellipsoid. Based on the relative size and distance between the influences from the Sun and the

Moon, the sun's effect on the tides is approximately 45% that for the Moon, depending on the location of the Earth in its elliptical orbit and proximity to the Sun (see [Figure T.49](#)).

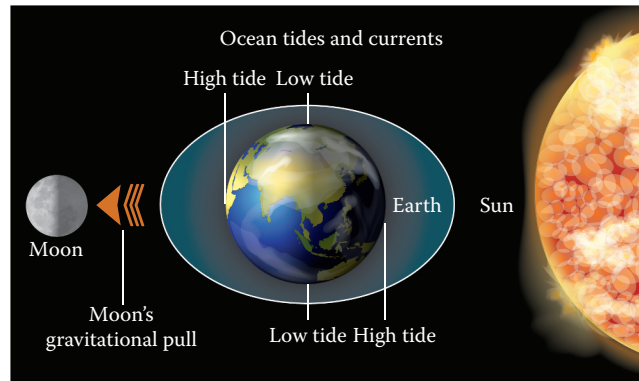


Figure T.49 Tidal forces. Influence of the position of both the Sun and the Moon of the tides by means of gravitational attraction on the liquid surface that can move freely.

Tidal motion

[general] Primarily observed for the earth's surface water. The oceans will be attracted to the MOON due to the gravitational interaction between the LIQUID mass and the mass of the Moon. The water surface closet to the Moon will be attracted with the greatest force, causing the highest elevation with respect to the average sea level (in the absence of CIRCULATION and external gravitational attraction). Water on the opposite side of the EARTH will experience attraction that will lower the water level with respect to "sea level" (see [Figure T.50](#)).



(a)

(b)

Figure T.50 (a,b) Tidal motion.

Tidal volume

[biomedical, fluid dynamics] (TV) During normal TIDAL BREATHING, the volume of inspired and expired AIR from the lungs. Tidal volume and other tidal breathing parameters can be measured with a spirometer (see Figure T.51).

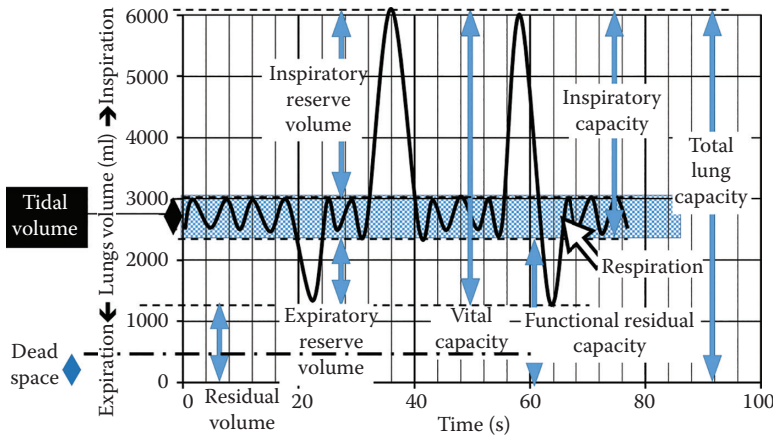


Figure T.51 Tidal volume.

Tidal waves

[fluid dynamics, geophysics] The small AMPLITUDE oscillation in a LIQUID with a free surface induced by GRAVITY. Tidal waves have an elegant solution to the WAVE EQUATION. Tidal waves can also be referenced as CANAL WAVES. In zero-order approximation, the wave equation for the surface wave can be treated as a wave traveling with no deformation in the surface contour. The Lagrange approach for solving the displacement uses the kinetic ENERGY (E_k) derived from the surface matrix of n coordinates (q_n) that vanish at equilibrium ($q_1 = q_2 = q_3 = q_4 = \dots = q_n = 0$), with respective velocities $v_i = \dot{q}_i = \partial q_i / \partial t$ described as $E_k = (1/2) \{ c_{11} \dot{q}_1^2 + c_{22} \dot{q}_2^2 + \dots + c_{nn} \dot{q}_n^2 + \dots + 2c_{12} \dot{q}_1 \dot{q}_2 + 2c_{23} \dot{q}_2 \dot{q}_3 + \dots + 2c_{n,n-1} \dot{q}_n \dot{q}_{n-1} \}$. The potential energy stored in the raised water level is similarly defined as $U_p = (1/2) \{ c_{11}' q_1^2 + c_{22}' q_2^2 + \dots + c_{nn}' q_n^2 + \dots + 2c_{12}' q_1 q_2 + 2c_{23}' q_2 q_3 + \dots + 2c_{n,n-1}' q_n q_{n-1} \}$. The Lagrange equation for the movement of the respective coordinates now becomes $(d/dt)(\partial E_k / \partial \dot{q}_i) - (\partial E_k / \partial q_i) = -(\partial U_p / \partial q_i) + D_i$, where D_i are the coefficients of displacement in the direction normal to the undisturbed surface, $i = 1, 2, 3, \dots, n$, describing the matrix of surface displacement as $D_1 \Delta q_1 + D_2 \Delta q_2 + \dots + D_n \Delta q_n$. This yields $D_i = c_i \ddot{q}_i + c_i' q_i$, where $\ddot{q}_i = \partial^2 q_i / \partial t^2$. The "forced" OSCILLATION solution now becomes $q_i = C_i / (c_i' - \tau_\pi^2 c_i) \cos(\tau_\pi t + \epsilon_\pi)$, where the wave has a period

$2\pi/\tau_\pi$, with $\tau_\pi^i = \sqrt{c_i^l/c_i}$, with C_i the coefficients for the simple harmonic solutions ($Q_i = C_i \cos(\tau_\pi t + \epsilon_\pi)$). Also referred to as Tidal Bore (see Figure T.52).



Figure T.52 Tidal bore, captured in Sumatra. (Courtesy of photographer Muhtar Sanusi and Antony Colas; www.bonosurf.com.)

Tide-generating forces

[fluid dynamics, geophysics] The gravitational attraction of the MOON in an orbit around the EARTH exerts a force on both the Earth and the free-flowing liquid on the surface, creating TIDAL WAVES. In large bodies of water (ocean and sea), this creates tidal waves. On the ebb and flood aspect of the main bodies of water, the rivers will drain or fill, creating canal tidal waves. The mass (m_{moon}) of the Moon at a variable DISTANCE (d_{moon}) from the Earth exerts a force that is dependent on the location on the earth's surface (with radius: r_{earth}) as well as the moon's zenith (the ANGLE with respect to a fixed meridian at longitude ϕ_{long} yields the ZENITH as a function of TIME (t) $\vartheta_{\text{moon}} = m_\omega t + \phi_{\text{long}} + f$, where ϕ represents the PHASE of the MOTION wavefunction and $m_\omega = r_{\text{earth}}\omega$, with ω the ANGULAR VELOCITY of the earth's revolution at a given location (P). The gravitational pull provides an ENERGY potential (U_Ω) that is linked by the gravitational constant (γ_{grav}) as $U_\Omega = (3/2)(\gamma_{\text{grav}} m_{\text{moon}} r_{\text{earth}}^2 / d_{\text{moon}}^3)[(1/3) - \cos^2(\vartheta_{\text{moon}})]$. The potential provides the horizontal acceleration vertically beneath the Moon in the tangential direction as $a_{//} = \partial U_\Omega / r_{\text{earth}} \partial \vartheta_{\text{moon}} = (3/2)(\gamma_{\text{grav}} m_{\text{moon}} r_{\text{earth}} / d_{\text{moon}}^3) \sin(2\vartheta_{\text{moon}})$; note that the Earth's gravitation (g) is linked to the mass of Earth (m_{earth}) to yield: $g = \gamma_{\text{grav}} m_{\text{earth}} / r_{\text{earth}}^2$. Similarly the SUN (mass: m_{sun} ; distance: d_{sun}) exerts a force that influences the tides in a similar fashion (i.e., presenting a cumulative effect). Now the equation of motion for the displacement (ξ) of the surface of the LIQUID with respect to "sea level," that is, the earth's surface): $\partial^2 \xi / \partial t^2 = v^2 (\partial^2 \xi / r_{\text{earth}}^2 \partial \phi_{\text{long}}^2) - (3/2)(\gamma_{\text{grav}} m_{\text{moon}} r_{\text{earth}} / d_{\text{moon}}^3) \sin(2[m_\omega t + \phi_{\text{long}} + \phi])$, where v is the speed of WAVE propagation. The AMPLITUDE A_{tidal} (i.e., the maximum range of low to high water during the semidiurnal period (T_{diurnal}) of the wave: $T_{\text{diurnal}} = 2\pi r_{\text{earth}} / m v$, with $n: 1 - \infty$) is represented for a uniform river basin floor bed as $A_{\text{tidal}} = r_{\text{earth}} [(3/2)(\gamma_{\text{grav}} m_{\text{moon}} r_{\text{earth}} / d_{\text{moon}}^3) / g] = r_{\text{earth}} (f/g)$. The "free" OSCILLATION solution to the wave equation under the influence of the Moon can be expressed under the FOURIER THEOREM as $\xi = -(1/4)[f r_{\text{earth}}^2 / (v^2 - m^2 r_{\text{earth}}^2)] \sin(2[m_\omega t + \phi_{\text{long}} + \phi])$, yielding for the physical perpendicular surface displacement: $\chi = -(1/2)[A_{\text{tidal}} v^2 / (v^2 - m^2 r_{\text{earth}}^2)] \cos(2[m_\omega t + \phi_{\text{long}} + \phi])$. Keeping in mind that the depth of the river will place a limiting factor on the wave phenomenon, not to have the amplitude exceed the depth. At great depths (as what may be found in the far off-shore ocean), the tidal wave will be antiparallel, or in counterphase (see TIDAL WAVE and TIDAL FORCE).

Timbre

[acoustics, general] The **FREQUENCY SPECTRUM** associated with the **SOUND** produced by an instrument. Often referred to as the “**COLOR**” of the sound. The introduction of higher harmonics by the instrument design and the way the primary tones are generated (the way the instrument is played) influence the spectral power profile as well as the range/expanse of the spectrum. For instance, for a wooden instrument, the local **HUMIDITY** will affect the elastic modulus of the casing for the **REVERBERATION** produced by an oscillating string. The elastic modulus will affect the **VIBRATION AMPLITUDE** as a function of wavelength. The choice of material can be instrumental in defining the sound quality as is the functional geometric design (shape and material thickness, etc.). For instance, the construction and finish (e.g., varnish) will be crucial; a Stradivarius violin still catches the attention of the audience after more than 300 years of **AGE**. The Stradivarius name was known as a family instrument makers business during the seventeenth and eighteenth century, particularly famous was Antonio Stradivari (1644–1737) for his skills in design, material selection, and material preparation as well as assembly (see [Figure T.53](#)).



Figure T.53 Metal straight flute.

Time (t)

[general] Sequence of events placed in relative respect to each other. Early concepts of time were attributed to the solar night–day rhythm (circadian rhythm), which as divided into two 12 segments by the Egyptians approximately 3000 years ago, defining the 24 h day. Persian mathematics (i.e., Babilonia) had the number 60 as the base (*Note*: the French arithmetic has the number 24 as base), which influenced the later subdivision of the hour into 60 min introduced in the fourteenth century when keeping track of time became more feasible with mechanical devices. As more intricate and accurate time keeping devices were developed, the minute was divided in 60 s. In 1967 a formal definition of the second as the standard of time was defined by the Si as the duration of 9192631770 oscillations of the **RADIATION** from cesium ^{133}Ce , the introduction of the **ATOMIC CLOCK**. The atomic clock in Boulder, Colorado, the United States is approximately 15.5 nanoseconds faster than the atomic clocks in Washington, DC, or Paris, France, which was indicated by **ALBERT EINSTEIN** (1879–1955) that time **MEASUREMENT** in this manner depends on **GRAVITY**. Early Babylonian and Egyptian time-keeping records used water flow and syphons as far

back as the sixteenth century BC. Additional early mechanisms of measuring used the Sun in the form of sundials (see [Figure T.54](#)).

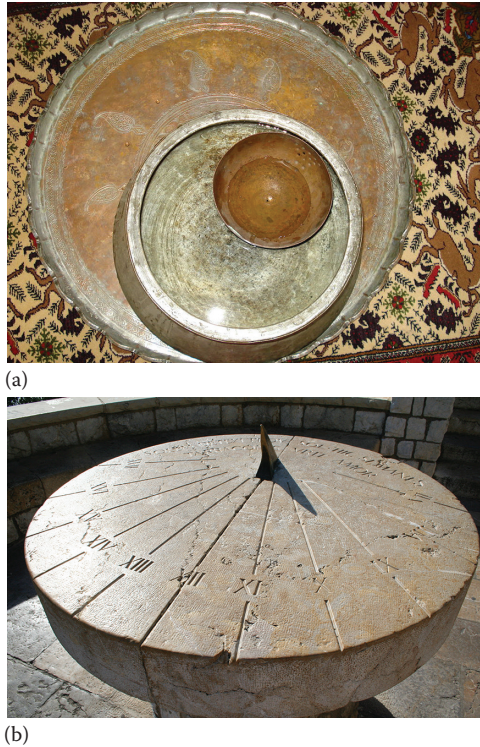


Figure T.54 (a) Ancient water clock and (b) historic sun dial.

Time dilation

[atomic, general, relativistic] See **DILATION**.

Time perturbation, colliding black holes

[astrophysics, general] In 1916 ALBERT EINSTEIN (1879–1955) predicted that under the concept of general relativity, the space-time CONTINUUM could be disrupted, making the UNIVERSE “ring.” At this point of time, no confirmed observations are documented for collisions of BLACK HOLES, nor has the time RIPPLE been measured. Based on theoretical considerations and the composition of the universe as we currently understand it, there may be small probabilities that black holes will collide in the next several million years, two black holes in the QUASAR PG 1302-102 can indeed merge. The two black holes are at approximately 3.5 billion light-years DISTANCE from our SOLAR SYSTEM. Another supposed double black-hole galaxy is NGC 6240, which is located at 140 million light-years from our solar system. This provides a better opportunity for two black holes, within the same GALAXY, to merge. So far the predictions indicate that this merger of two black holes in the NGC 6240 galaxy will at least not happen for another 100 million years. The MILKY WAY itself is supposedly meeting up with the ANDROMEDA GALAXY in several billion years from now, as we approach at 120 km per SECOND. In general, when galaxies merge, the central black holes of the respective galaxies will be placed in orbit with each other. Several known galaxies have been shown to have a BLACK HOLE at its center. The Milky Way has a confirmed central black hole at a distance from our solar system of approximately 28,000 light-years (*Note:* estimate diameter of the Milky Way is 100,000 light-years). The anticipated perturbations in the spacetime continuum (e.g., ripples in time) resulting from black-hole collisions are

represented by “GRAVITATIONAL WAVES.” The Einstein Equations elegantly allow the unification of space and time into a format known as “SPACETIME.” When trying to solve for impact on either space (GRAVITY) or time the Einstein equations will need to be decomposed so that mathematical approach reverts to the “Cauchy problem” (mathematician from France: BARON AUGUSTIN-LOUIS CAUCHY (1789–1857)). During a collision of two black holes in approximation roughly 0.1% of the mass of the merged system is “radiated away” as gravitational waves. The impact on “pure time” can be imagined in the SPACETIME representation by means of expression of points with coordinates of both space and time. Slices in the SPACETIME of constant time will intersect with spatial coordinates. The lapse in “proper time” (as we live it) can be derived using the decomposition of the EINSTEIN EQUATIONS in the Cauchy problem version specific to solving partial differential equations on a hypersurface in a multidimensional domain. The Cauchy problem consists of finding the SOLUTION u of the differential equation for the functions f_k on the surface S of order m that satisfies $\partial^k u(x)/\partial n^k = f_k(x)$ $\{k = 1, 2, 3, m-1\}$, where n is the normal vector to the surfaces, which is known as the Cauchy data, under the boundary condition $u(x) = f_0(x)$. Under SPECIAL RELATIVITY, the spacetime continuum is considered to be “flat,” meaning no change in time associated with changes in gravitational MOTION. In this case, the interval (ds) between two points in space and time is defined as $x^a = (t, x^1, x^2, x^3) = t \begin{pmatrix} 1 \\ x^i \end{pmatrix}$, with concurrent changes $x^a + dx^a = (t + dt, x^i + dx^i)$, which can be rewritten using the PYTHAGOREAN THEOREM as $(ds)^2 = -dt^2 + (dx^1)^2 + (dx^2)^2 + (dx^3)^2 = \sum_{a,b} \eta_{ab} dx^a dx^b$. The matrix is normalized by means of the Minkowski metric TENSOR (Russian mathematician HERMANN MINKOWSKI (1864–1909)): η_{ab} with diagonal $\eta_{ab} = \text{diag}(-1, 1, 1, 1)$. In this interval, the time (τ) is defined by means of proper time under the condition $d\tau^2 = -ds^2$, that is, less than zero. Under general relativity, specifically when “SPACETIME” is curved, the Minkowski metric tensor changes to provide the tools for $(3 + 1)$ decomposition (representing the Cauchy problem) as g_{ab} ; $ds^2 = \sum_{a,b} g_{ab} dx^a dx^b$. The $(3 + 1)$ decomposition constraints the gravity fields (in the EINSTEIN EQUATIONS) for every instance of time, and allows for an additional time perturbation of the gravitational fields, thus splitting the SPACETIME into space and time. In the $(3 + 1)$ decomposition SPACETIME can be considered to be foliated into slices defined by constant time coordinates. In the $(3 + 1)$ decomposition, spacetime “points” are connected by vector t^a , using a time vector that stands normal to the SPECIAL RELATIVISTIC space, defined as n^a . The SPACETIME slices will be separated by dt , defined by a lapse function α_{lapse} . The “lapse function” relates to “proper time” (as we live it) in SPACETIME in the displacement (dx^a) between two points $[A^{x^i, t}$ and $B^{x^i + dx^i, t + dt}]$ written using the Pythagorean theorem as $ds^2 = -\alpha_{\text{lapse}}^2 + \sum_{i,j} \gamma_{ij} (dx^i + \beta^i dt)(dx^j + \beta^j dt)$, where γ_{ij} is a quantity defining the spatial separation between the two SPACETIME slices. Under these conditions, the curvature in SPACETIME is defined by the time derivative of the spatial metric γ_{ij} to yield the extrinsic curvature K_{ij} (see Figure T.55).

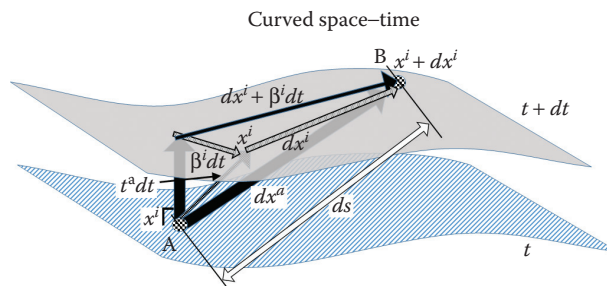


Figure T.55 Geometric representation of space–time described under the conditions of curved space. The transition between two points in the spacetime matrix is described by general relativity methods.

Timocharis

[astrophysics, general] Fourth century BC, Greek scientist and astrophysicist. Together with ARISTYLLUS, they documented the first list of visible fixed stars.

Tip angle

[energy] **ANGLE** of airplane **WING** with a horizontal reference plane, with the vertical plane in which the **PROPELLER** rotates (ship, wind **TURBINE**). The tip angle changes during the take-off for an airplane, and can be adjusted for a wind turbine or old-fashioned windmill to adjust for influences generated by the wind direction, wind velocity, as well as desired performance. The tip angle for a plane obtaining a cruising altitude, steady-state flight, is also referred to as the tip-settling angle. For a propeller (airplane engine, ship/motor-boat, and wind turbine), there is an angle associated with the performance (efficacy and efficiency). Also referred to as the turbine blade angle (see [Figure T.56](#)).

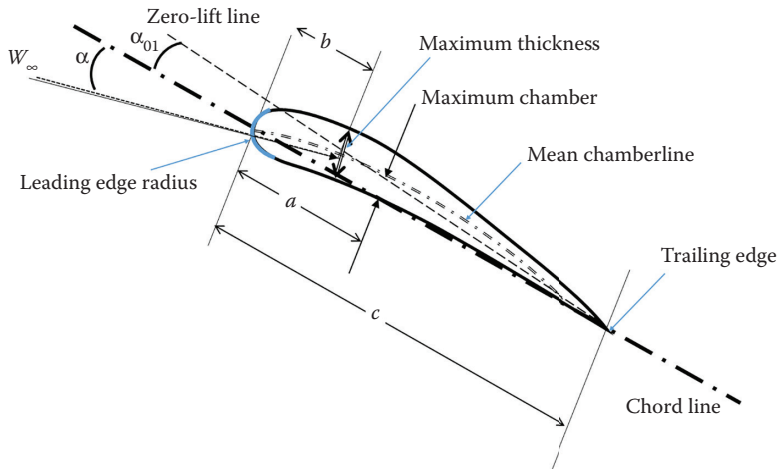


Figure T.56 Tip angle of an airplane wing.

Tissue characterization

[acoustics, biomedical, imaging] Mechanism-of-action applied in acoustic (**ULTRASOUND**), optical, magnetic (**MRI**), **X-RAY**, or positron emission (**PET**) imaging to identify the characteristic properties that allow for discrimination between tissue functionality, tissue composition, and tissue density. The parameters used for characterization can be any of the following with their respective potential for identification: **FREQUENCY SPECTRUM** (tissue type or stage of development: collagen/fat/bone; **METABOLIC ACTIVITY**; general subjective health: “you don’t look so good”); attenuation (elastic modulus, density, phase [liquid/solid]); and refraction/reflection (boundary detection). Under certain circumstances, a “tag” is required to assist in the characterization process; for **PET**, this tag is fluorine-18-fluorodeoxyglucose, which acts as **GLUCOSE** but has a specific positron **EMISSION SPECTRUM** that can be acquired as a function of location hence revealing the local metabolic activity. These imaging methods can be applied *in vivo*. The other imaging technique performed *ex vivo* is optical microscopy. Optical imaging generally requires staining with dyes and chemicals for visible or fluorescent recognition of **CELL** types in order to screen for deviations from the norm. One optical technique that can provide *in-vivo* imaging is **OPTICAL COHERENCE TOMOGRAPHY**, which can apply all the optical features (**PHASE**, wavelength, **MAGNITUDE**, and combinations of factors to reveal physiological features next to anatomical features). Another relatively new imaging technique is photoacoustic imaging, combining

the acoustic and optical modalities to reach deeper than standard optical imaging and provide acoustic RESOLUTION (see Figure T.57).

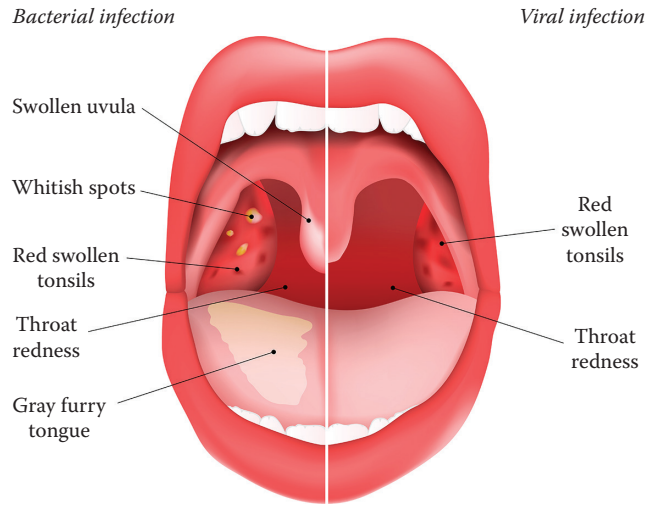


Figure T.57 Visual rudimentary characteristics of the appearance of tissue under (left) bacteria compared to tonsillitis of the throat and (right) viral versus bacterial infection diagnosis.

Titanium

[biomedical, mechanics, solid-state] Chemical ELEMENT, metal: $^{48}_{22}\text{Ti}$. Titanium was discovered in 1791 by William Gregor (1761–1817); it is a very strong and light-weight METAL with a silver COLOR with a relatively high MELTING POINT (1941K, compare to 1811K for IRON; 1357 K for copper). Titanium has excellent biocompatibility, no toxic effects, and is resistant to the acidic nature for decades of functional use. Titanium is used in durable devices such as JET engines, missiles, automotive/motorcycle, orthopedic implants, and implantable defibrillators/pacemakers. Titanium can form alloys with several other metals: iron, aluminum, vanadium, and many more. Titanium is an excellent CONDUCTOR of electrical current. Titanium alone does not function well as a biological ELECTRODE due to POLARIZATION effects. The use of Titanium for electrode material will result in a gradual loss of signal AMPLITUDE as a result of the localized charge accumulation.

Toepler, August Joseph Ignaz (1836–1912)

[biomedical, energy, general, optics] Physicist from Germany (Prussian Empire) who made several discoveries related to electrostatic behavior next to investigations in fluids. In his analysis of FLUID flow and associated shock waves, he applied Foucault's knife-edge test for TELESCOPE mirrors (1864) as a mechanism for imaging. He is credited with describing the heat-induced BIREFRINGENCE in materials in 1894. The imaging mechanism under the birefringence discovered by August Toepler was characterized

as SCHLIEREN IMAGING. Schlieren imaging has only had limited applications so far, but is gaining interest (see [Figure T.58](#)).

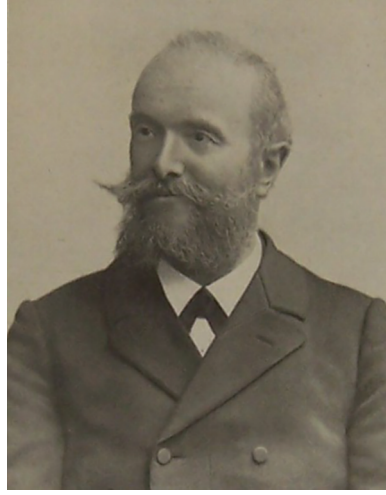


Figure T.58 August Joseph Ignaz Toepler (1836–1912). (Courtesy of Österreichische Zentralbibliothek für Physik 1908.)

Tokamak Fusion Reactor

[general] REACTOR accelerator designed for NUCLEAR FUSION based on a close to ideal toroidal MAGNETIC FIELD. The name is a Russian acronym that loosely translates into “toroidal chamber with magnetic coils.” The toroidal confinement provides the boundary conditions for theoretical stability of a PLASMA in equilibrium. The specific plasma confinement is provided by an additional poloidal magnetic FLUX in the toroid, which provides conservation of the canonical angular momentum. The toroidal canonical angular momentum conservation results in a characteristic closed orbit. The plasma is initially created as the result of ohmic current interactions with an ionizing gas. The plasma is confined by “scraping off” the outer layer using a diverter separatrix, preserving the D-shaped tokamak plasma. The tokamak principle and prototype were constructed by the physicists from Russia (USSR: Union of Soviet Socialist Republics; in short Soviet Union) Igor Tamm (1895–1971) and Andrei Sakharov (1921–1989), in the 1950s (see [Figure T.59](#)).

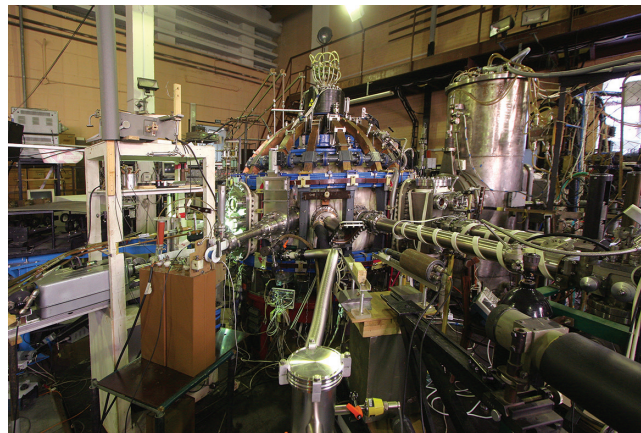


Figure T.59 Image of the Tokamak Fusion Reactor design.

Tomographic slices

[biomedical, imaging] In order to view the content of any three-dimensional construction, one will require a SLICE to observe the pertinent information within the structure. There are several ways of slicing a tomographic reconstruction, primarily axial (a slice of the body on the axis of the body); coronal (a view of a plane that is parallel to the plane marked out by the extremities; arms and legs); and a sagittal view that carves the body from anterior to posterior, dividing left and right side of the body at various distances from the center (see [Figure T.60](#)).

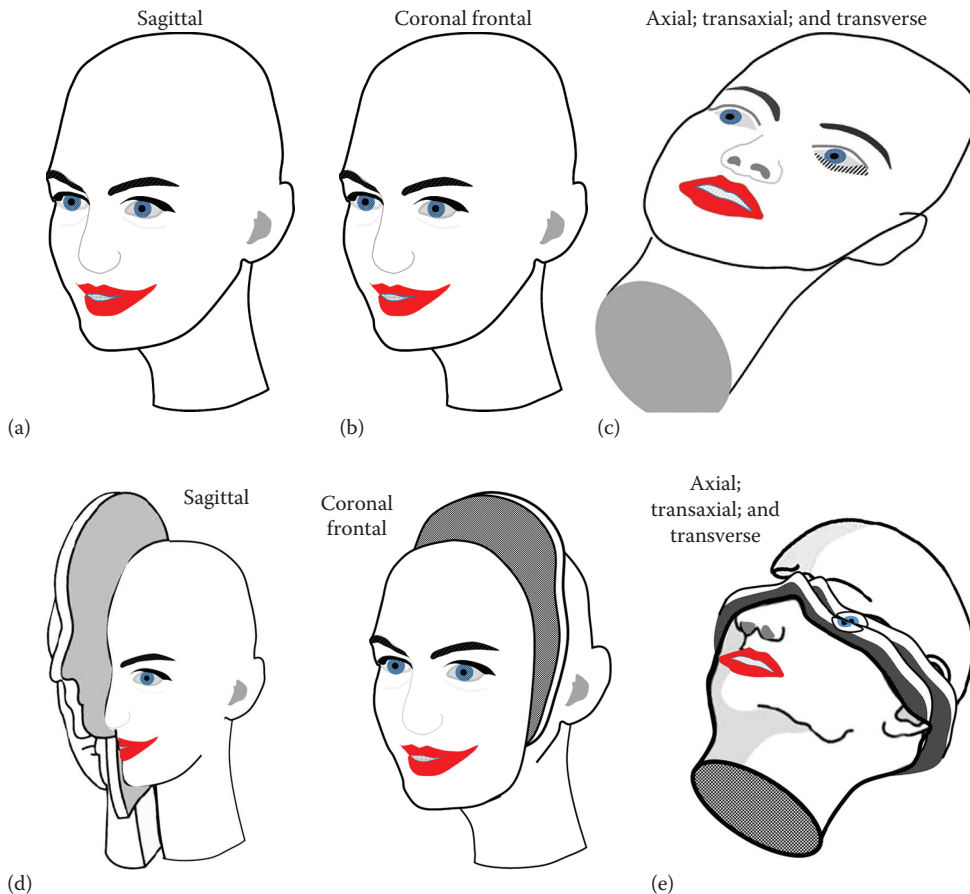


Figure T.60 (a–e) Designation with respect to tomographic slice configuration. (e: Adapted from Prince, J.L. and Links, J., *Medical Imaging Signals and Systems*, Pearson Education, Upper Saddle River, NJ, 2006.)

Tomography

[acoustics, biomedical, electromagnetism, imaging] Two- or three-dimensional reconstruction of an IMAGE formed by probing line-of-flight radiation. Generally the source to detector correlation is on opposing sides of a circular band; the sensors are simultaneously collecting at multiple locations from within the same toroidal configuration. The RADIATION can be X-RAY, RADIONUCLIDE positron emission from artificially induced radioactive isotopes that generates the release of two perfectly opposite gamma ray photons (PET) and line-of-sight capture of radiofrequency RESONANCE signals induced by magnetic fields (MRI). An additional form of tomography uses geometric reconstruction based on the BACKSCATTER of LIGHT under optical coherence tomography (OCT), where the scanning pattern defines the extend of the two-dimensional outline, with the depth providing the third dimension. The depth of OCT probing is confined by the SIGNAL strength collected form depths of several micrometers from OPAQUE media (see [Figure T.61](#)).

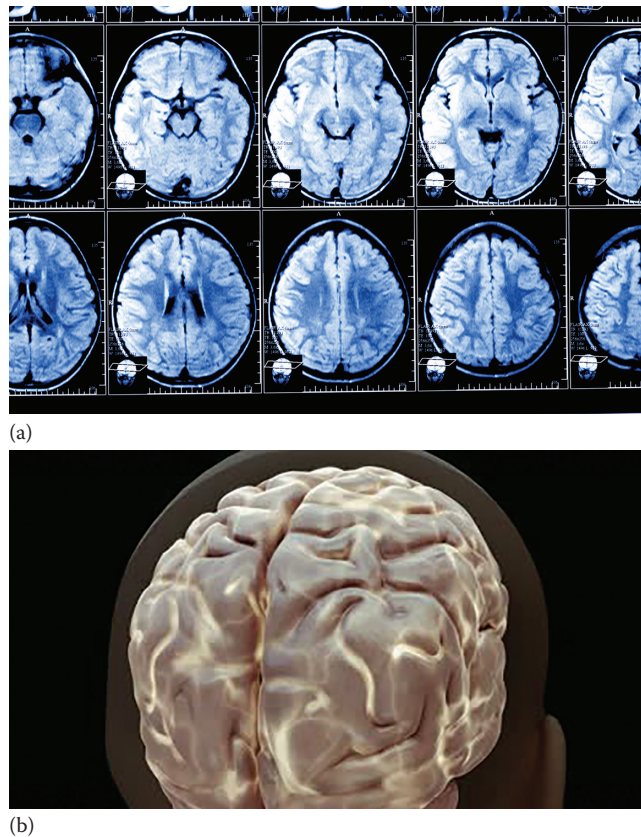


Figure T.61 Tomography: (a) CAT scan of the brain; computer assisted tomography; imaging with X-ray and (b) three-dimensional rendering of the brain from acquired images slices.

Tomonaga, Sin-Itiro (朝永 振一郎) (1906–1979)

[general] Physicist from Japan. Sin-Itiro Tomonaga received the Nobel Prize in Physics in 1965 for his contributions to quantum PHYSICS theory, specifically quantum ELECTRODYNAMICS. He shared the Nobel Prize with RICHARD FEYNMAN (1918–1988) and Julian Schwinger (1918–1994). Sin-Itiro Tomonaga performed experimental verification of the pair creation of the PHOTON–electron pair in 1939, and worked closely with WERNER HEISENBERG (1901–1976) in Germany. On his return to Japan, he developed the theoretical definition of the MESON cloud around the NUCLEON. In 1942, he proposed the covariant field theory, in which the QUANTUM STATE was also relativistically covariant (see [Figure T.62](#)).

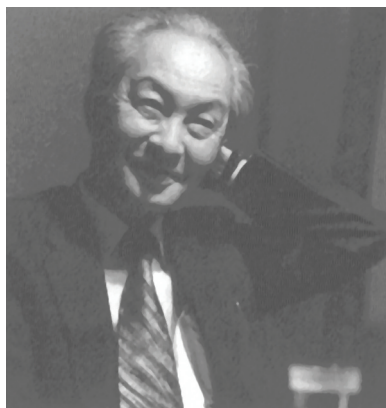


Figure T.62 Sin-Itiro Tomonaga (朝永 振一郎) (1906–1979). (Courtesy of University of Chicago Press, Chicago, IL.)

Tonicity

[biomedical, chemical] Expression of the OSMOTIC PRESSURE gradient across a SEMIPERMEABLE MEMBRANE (such as a CELL MEMBRANE) of two ionic/molecular solutions. Due to the fact that the cell membrane of most mammals is permeable to only a select few ions and molecules and highly diffusive to water, the changes in concentration of certain cellular constituents can result in the release or gain of water. The release of water as a result of OSMOSIS will result in cell shrinkage. Alternatively when the extracellular FLUID is diluted, the cell will gain water and will swell. A swollen cell will activate its sodium, potassium, and chlorine channels, resulting in an efflux primarily of K^+ and Cl^- due to the difference in mobility. This chemical exchange will not affect the MEMBRANE POTENTIAL, due to the opposite charge signs

involved. Both cell swelling and shrinking will dramatically impair the function of the cell, potentially resulting in cell death (see [Figure T.63](#)).

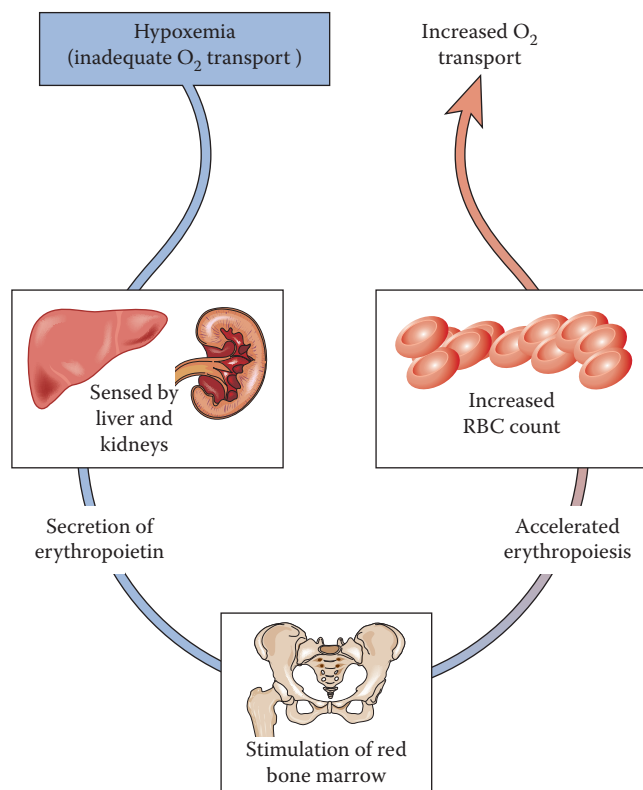


Figure T.63 Hypoxemia.

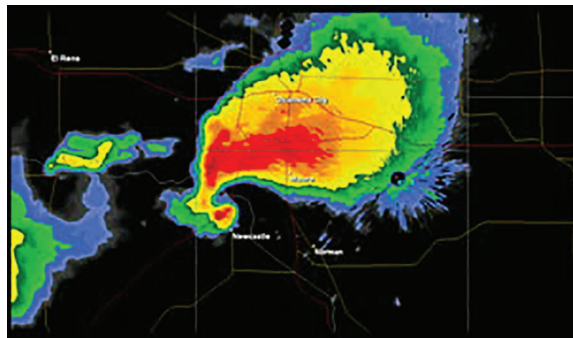
Tornado

[fluid dynamics, geophysics, mechanics, meteorology] Air-flow vortex of large proportions. Note that tornadoes are different from hurricanes, although hurricanes can *SPIN* off tornadoes. The rotation of a column of *AIR* can touch the surface while stretching out into cumulonimbus clouds, and on rare occasions may reach upward to the cumulus cloud portion of the *ATMOSPHERE*. Tornadoes form as a result of converging air masses from different directions, specifically the convergence of a cold and a warm airstream. The tornado is generally preceded by a rotation in the upper atmosphere that is observed in geological radar stations that observe the formation and precipitation of *RAIN* and snow clouds, at the level of cumulonimbus clouds. Tornadoes are also referred to as twisters or as cyclones and are found all over the world. The majority of tornadoes occur in what is known as Tornado Alley in the central part of the United States. Tornado Alley stretches from south to north starting in Texas, going through Oklahoma, Kansas, Nebraska, and North and South Dakota. The Tornado Alley gains its reputation from warm Gulf of Mexico air colliding with cold air from Canada and the Arctic. Tornadoes can have a diameter of over 75 m to close to 2 km. Small tornadoes travel slowly, at about 40 km per hour, whereas speeds up to 300 km per hour have been clocked for large tornadoes. A strong and destructive tornado is referenced as an F-5, whereas lower numbers are less potent. Tornadoes last from several minutes to, rarely, one hour. Due to Coriolis forces, tornadoes on the northern hemisphere turn counterclockwise and clockwise on the southern hemisphere. The F-scale is derived from Tetsuya Fujita (1920–1998) who designed the scale based

on anticipated or experienced destruction. The VORTEX phenomenon can LIFT entire houses of their foundation, and the accompanying pressure gradient will shatter most windows within its path and direct vicinity (see [Figure T.64](#)).



(a)



(b)

Figure T.64 Tornado: (a) Doppler radar image of air stream flow velocity and direction during a tornado and (b) diagram of the outline of a tornado.

Torque (τ)

[general] The sum of the tangential components of the net LEVER force multiplied by the DISTANCE from the point of rotation to the point where the forces are applied, that is, the MOMENT ARM.

Torque is mathematically defined as $\vec{\tau} = \sum \vec{F} \times \vec{r}$. Torque resulting in clockwise rotation is positive, whereas counterclockwise rotation has a negative torque (see [Figure T.65](#)).



Figure T.65 Torque wrench with dial for indication of applied torque.

T

Torr

[general] Unit of pressure, equivalent to 1 Torr = 1 mmHg = 133.3 Pa on the MERCURY BAROMETER scale (see EVANGELISTA TORRICELLI [1608–1647]).

Torrey, Henry Cutler (1911–1998)

[atomic, imaging, nuclear] Physicist from the United States who contributed to the theoretical understanding of nuclear MAGNETIC RESONANCE. The work of Henry Torrey provided significant advancement of magnetic resonance imaging (MRI), in collaboration with EDWARD MILLS PURCELL (1912–1997) and ROBERT VIVIAN POUND (1919–2010), based on the earlier work of ISIDOR RABI (1898–1988) and FELIX BLOCH (1905–1983).

Torricelli, Evangelista (1608–1647)

[fluid dynamics, general, geophysics, meteorology]: mathematician and physicist from Italy, protégée of GALILEO GALILEI (1564–1642). Following in the footsteps of Galileo and his work with experimental observations on the “weight” of AIR (glass bulb), Torricelli realized the cause and effect in 1643. His work in COMMUNICATING VESSELS led to the construction of a device to measure the fluctuating pressure in the ATMOSPHERE with changing weather conditions, or better in anticipation of changing weather conditions. The TORRICELLI BAROMETER was confirmed and details were added by BLAISE PASCAL (1623–1662) in 1648. Torricelli lent his name to the TORR or mmHg (millimeter mercury) as a unit for pressure, mostly used for low pressure, whereas the PASCAL (Pa) is the recognized standard unit for pressure (see Figure T.66).



Figure T.66 Evangelista Torricelli (1608–1647).

Torricelli's barometer

[fluid dynamics] Barometer as introduced by EVANGELISTA TORRICELLI (1608–1647) around 1643 that consists of a GLASS tube inserted in a bowl of mercury. The tube is closed on the top, and the ATMOSPHERE provides a column of AIR resting on the surface of the mercury in the bowl, raising the mercury level. GALILEO GALILEI (1564–1642) had already determined that air has mass (weight), which led Torricelli to the correlation and derived the pressure resulting from a tall volume of air surrounding the globe as a function of weather conditions and altitude. The location-dependent pressure variability was derived in collaboration with BLAISE PASCAL (1623–1662) in 1648. The same principle was applied to measure BLOOD

pressure in 1726. The first recorded attempts to measure BLOOD PRESSURE are the work of the clergyman, astronomer, chemist, and botanist from Great Britain, Stephen Hales (1677–1761). The reverend Stephen Hales used a brass PIPE (one-sixth of an inch in diameter) connected to a narrow glass tube and attached it to the carotid artery of a horse to investigate what was ailing the dying animal. The tube was 12' 9" tall (388 cm) and the blood reached approximately 8 feet in height (2.44 m). Repeating his experiments for other locations and with other animals, he was able to provide a diagram of blood pressure distribution based on the ANATOMY and DISTANCE to the HEART for several animals and developed a system to apply this to humans as well. This fluid-dynamics system has considerable DAMPING and provides an average pressure value. For humans, Hales concluded a pressure of 7' 6" (apparently based on hypothesis), corresponding to a SYSTOLIC PRESSURE of 176 mmHg on "modern" standards. This type of MEASUREMENT was performed on humans by a French surgeon in 1820 providing the equivalent of 120 mmHg on the femoral artery when his patients had to have a LEG amputated. In 1876, the first SPHYGMOMANOMETER was developed that measures the corresponding blood pressure on the wrist by means of a balloon pressed against the radial artery (as connected to the brachial artery that is currently used to measure the blood pressure in the elbow). The wrist sphygmomanometer was developed by Karl Samuel Ritter Von Basch (1837–1905) from Czechoslovakia (now Czech Republic). In 1896, the Riva Rocci Sphygmomanometer was developed, which measures the blood pressure at the elbow and is the predecessor to the current state-of-the-art device. It was not until 1904 that the Russian army surgeon NIKOLAI KOROTKOFF (1874–1920) realized that closing off the brachial artery allowed for measuring the systolic versus DIASTOLIC PRESSURE using the fluttering sounds of blood rushing through a pinched blood vessel (KOROTKOFF SOUNDS) (see MERCURY BAROMETER, BLOOD PRESSURE, and NIKOLAI KOROTKOFF) (see Figure T.67).

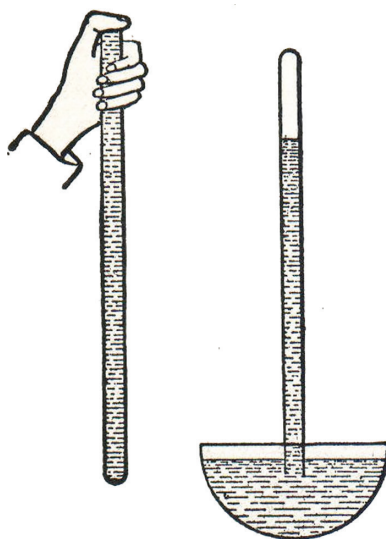


Figure T.67 Torricelli barometer.

Torsion

[computational, general, mechanics] In mechanical ENGINEERING, this refers to the mechanical twisting of an object under the influence of an applied torque. The mechanical torsion is represented by the torque τ_T , defined by the shear stress in the twisted material on the outer surface (σ_s^*), the material properties imbedded in the torsion constant (J_τ), as a function of the DISTANCE of the farthest point out from the rotational axis of symmetry to the outer surface (r) expressed as $\tau_T = (J_\tau/r)\sigma_s^* = (J_\tau/\ell)G_\sigma\theta$, where G_σ is the shear modulus for the material and geometry (also referred to as the MODULUS OF RIGIDITY), θ the ANGLE OF

rotation/twist in the material with respect to relaxed state, and ℓ is the length over which the torque is applied. In ALGEBRA, the torsion characterizes the twisting of a moving reference frame around a curve. The torsion TENSOR ($T(\mathbf{X}, \mathbf{Y})$) defining the manner in which a moving frame is screwed around a state curve is described with respect to the vector fields $\mathbf{X}$ and $\mathbf{Y}$ as $T(\mathbf{X}, \mathbf{Y}) = \nabla_{\mathbf{X}}\mathbf{Y} - \nabla_{\mathbf{Y}}\mathbf{X} - [\mathbf{X}, \mathbf{Y}]$. In this notation, $[\mathbf{X}, \mathbf{Y}]$ represents the Lie bracket of vector fields, the Lie derivative $\mathcal{L}_{\mathbf{X}}\mathbf{Y} = \lim_{t \rightarrow 0} [((d\Phi_t^{\mathbf{X}})\mathbf{Y}_{\Phi_t^{\mathbf{X}}(x)} - \mathbf{Y}_x)/t]$, where $\Phi_t^{\mathbf{X}}$ represents the flow associated with the vector field, and $d\Phi_t^{\mathbf{X}} = \partial \hat{\Phi}^{\mathbf{X}} / \partial u^i$ is the tangent map derivative operator applied to the flow field, providing the linear map of the differential of $\Phi_t^{\mathbf{X}}$, $\hat{\Phi}$ the smoothed vector field $\Phi_t^{\mathbf{X}}$, and u the transform of x in the vector flowchart (see Figure T.68).

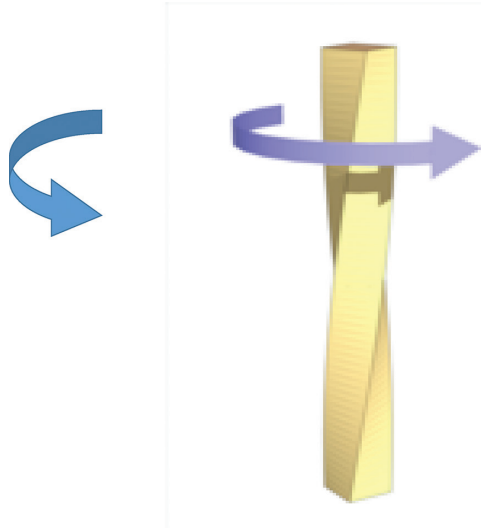


Figure T.68 Torsion.

Torsion wave

[fluid dynamics, general, mechanics] Under rotational agitation of a FLUID or solid, the harmonic perturbation will travel forming a torsion wave. For instance, the axle of a car is under continuous torsional forces that vary with time, hence creating a torsional wave, specifically the use of the torsion bar suspension. Another example is in the vertical agitating top-loader washing MACHINES (driven torsional OSCILLATION). The torsion wave (*also see DAMPED HARMONIC MOTION and FORCED VORTEX*) (see Figure T.69).



Figure T.69 Torsion wave. (Courtesy of Kay Wyatt.)

Torsional oscillations

[fluid dynamics, general, mechanics] Two prime examples of TORSION WAVE are for a hollow sphere filled with viscous LIQUID oscillating around its vertical axis and a sphere oscillating around its vertical axis surrounded by viscous liquid. The vertical agitating laundry washing machine found in the United States and Great Britain and other locations (different from the front-load washing machine) would be the cylindrically symmetric version for the spherical oscillation surrounded by a viscous liquid. The situation for the hollow sphere with radius R , oscillating at an ANGULAR FREQUENCY ω , that is filled with viscous liquid will have PARTICLE movement as a function of radius described by $\omega' = \left[\psi_1(br) / \psi_1(bR) \right] \omega$, where $b^2 = -(\sigma_\omega / \nu_{\text{kin}})$ represents the “functional” DISTANCE from the center on the rotating axis, $\nu_{\text{kin}} = \eta_{\text{kin}} / \rho$ the coefficient of KINEMATIC VISCOSITY (η_{kin} the kinematic viscosity, ρ the density), $\sigma_\omega = \nu_s k$ the angular velocity of rotational motion (ν_s the wave propagation velocity), and ψ_1 is the first-order spherical harmonic component. The general SOLUTION to the WAVE EQUATION, $(\nabla^2 + k^2)\phi(r, \theta, \varphi) = 0$, provides $\phi = \sum \{ A\psi_n(kr) + B\Psi_n(kr) \} r^n S_n$, where A and B are constants, k is the wavenumber, and S_n represents the surface harmonic of order n . The functions are linked to BESSEL FUNCTIONS ($J_k(\xi)$), of the order $\pm(1/2)(2m+1)$, as $\xi^n \psi_n(\xi) = \sqrt{[(\pi/2\xi) J_{n+(1/2)}(\xi)]}$; $\xi^n \Psi_n(\xi) = (-1)^n \sqrt{[(\pi/2\xi) J_{-n-(1/2)}(\xi)]}$, respectively $\psi_n(\xi) = 1/1.3 \dots (2n+1) \{ 1 - [\xi^2/2(2n+3)] + [\xi^4/2.4(2n+3)(2n+5)] - \dots \}$ and $\Psi_n(\xi) = 1.3 \dots (2n+1) / \xi^{2n+1} \{ 1 - [\xi^2/2(1-2n)] + [\xi^4/2.4(1-2n)(3-2n)] - \dots \}$. Due to the fact that the MOTION at the central axis (origin) is finite (no motion on the vertical axis) only the term $= A\psi_n(kr) r^n S_n$ is retained. The sphere will be suspended by the external axis. The angular velocity on the axis for the liquid within the sphere will need to be zero under consideration of ENERGY constraints. For the viscous liquid inside the rotationally oscillating sphere there are two situations: low- or high-viscosity medium. The high-viscosity case yields (the Stokes theorem): $\omega' = \left[\psi_1(br) / \psi_1(bR) \right] \omega = \omega \cos(\sigma_\omega t + \epsilon)$, where ϵ is the phase shift. Under these high-viscosity OSCILLATION conditions, the net torque (sometime also described as “couple”) is given as $\tau_F = (8/3)\pi\eta_{\text{kin}}R^3 \left[b^2 R^2 \psi_2(br) / \psi_1(br) \right] \omega$. In contrast, the low-viscosity case changes the boundary conditions to include more elaborate details: $2i\psi_n(bR) = [-(d/\xi d\xi)]^n (e^{i\xi}/\xi)$. The low-viscosity oscillation yields for the torque as a function of time $\tau_F = -(4/3)(\pi\rho R^5/\beta'\sigma_\omega) (d\omega/dt) - (8/3)\pi\eta_{\text{kin}}R^3(\beta'\sigma_\omega)\omega$, where the first term is an indication of the INERTIA of the sphere, the second term introduces DAMPING from FRICTION, and $\beta' = \sqrt{(\sigma_\omega/2\nu_{\text{kin}})}$ represents the reciprocal viscous influence, a scaling factor. Next the torsional oscillating sphere around its vertical axis surrounded by viscous liquid is discussed. Under these conditions, the outside medium is assumed to have an infinite radius. Due to the infinity condition, the solution reduces to functions of the first class ($n=1$) only. The torque on the oscillating sphere due to the outside viscous medium is now, in complex notation (accounting for damping), $\tau_F = -(8/3)\pi\eta_{\text{kin}}R^3 [(3+3ibR-b^2R^2)/(1+ibR)]\omega$. This torque reduces for long period to $\tau_F = -8\pi\eta_{\text{kin}}R^3\omega$, the negative sign indicates the counteracting influences of the viscous friction. A special case for this would be the harmonic rotation of a sphere within a sphere (*also see FORCED VORTEX*) (see Figure T.70).



Figure T.70 Torsional oscillation for a top-load washing machine.

Total angular momentum

[atomic, nuclear] The general mechanics definition of angular momentum is $\vec{L} = \vec{r} \times \vec{p} = \vec{I} \times \vec{\omega}$, $\vec{p} = m\vec{v}$, where I is the MOMENT OF INERTIA for the device and its orientation, r the radius, and v is the velocity of the object with mass m moving at a DISTANCE r . On a quantum-mechanical scale, the orbital angular momentum can be coupled to the SPIN angular momentum for the same electron, providing the respective total angular momentum. Similarly, the angular momentum of the NUCLEUS also provides its own influences. The total angular momentum on the quantum-mechanical level is defined by the orbital quantum number (ℓ) and spin quantum number ($s = \pm 1/2$) with QUANTUM NUMBER $j = \ell \pm (1/2)$, yielding $J = \sqrt{j(j+1)}\hbar$, where $\hbar = h/2\pi$, $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ is the PLANCK'S CONSTANT; with $(2j+1)$ z -projections $J_z = m_j\hbar$.

Total internal reflection

[general, optics] Under SNELL'S LAW of refraction $n_1 \sin \theta_1 = n_2 \sin \theta_2$ (the subscript $\square$ identifying the specific medium, n the index of refraction, and θ is the ANGLE with the normal to the surface at the interface), the ratio of index of refraction for the two media at a boundary can become smaller than 1 when the originating medium is more dense than the bordering medium. At a certain angle of incidence, the refraction angle becomes $90^\circ = \pi/2$, at which point the LIGHT will continue parallel to the interface after incidence. At greater angles of incidence, the electromagnetic RADIATION will be reflected, obeying the LAW OF REFLECTION: $\theta_r = \theta_i$. This phenomenon can render items "invisible" under water due to the viewing position of the observer with respect to the object at a great linear DISTANCE.

Total loss

[fluid dynamics] For a flow in a pipeline, the factors contributing to losses in ENERGY are the following: entrance loss; frictional loss due to shear at the WALL, frictional losses in elbows, valve orifices, friction losses in discharge branch off line (bi-, trifurcations, etc.), exit loss due to EXPANSION, next to the elevation of the flow (z). The respective head-loss factors add up as $h_{L,T} = K_i(v_s^2/2g) + [f_s(L/D)(v_s^2/2g) + f_d(L/D)(v_d^2/2g)] + \{K_b(v_s^2/2g) + [f_{dT}(L_e/D)_{\text{elbow}}(v_d^2/2g)]_{90^\circ}\} + f_{dT}(L_e/D)_{\text{valve}}(v_d^2/2g) + \text{branch-off} + K_e(v_d^2/2g) + (z_2 - z_1)$, where the average velocity can be derived from the flow rate (Q) as $v_s = \dot{Q}/A_s$ (A_s the total suction line exit cross-sectional area), $v_d = \dot{Q}/A_d$ (A_d the total discharge line exit cross-sectional area), f_s and f_d the FRICTION factor for suction and discharge respectively, D the tube diameter (assuming a constant diameter for the main section, the FLUID under consideration will provide the COEFFICIENT OF FRICTION (v_{kin}) and overall friction (η_{kin}). The REYNOLDS NUMBER for the flow yields information about the flow structure (turbulent or laminar), $Re = v_s D \rho / \eta_{\text{kin}}$, for both the main line and the respective discharge line(s). One important consideration is the RELATIVE ROUGHNESS of the wall $\chi_r = D/\epsilon_s$, where ϵ_s is the average "height" of the raised and carved general unevenness in the surface. The relative SURFACE ROUGHNESS (listed in reference tables, material property) in combination with the Reynolds number will provide the respective friction factors from Moody's diagram. The entrance coefficient K_i is a function of the shape, $K_i = 0.5$ for square edges; $K_i = 1$ for round outflow, similarly for the branches K_b and exit flow K_e . The values $(L_e/D)_{\text{valve}}$ for a valve, $(L_e/D)_{\text{elbow}}$ for an elbow can be found in design tables. The power supplied to enforce the flow in this case is $P_f = h_{L,T} \rho_f \dot{Q}$, where ρ_f is the fluid density. Incorporating

the pump efficiency γ_f will provide the operational requirements for the PUMP (in kwatt or horse power), where the electric pump quickly reach 75% efficiency (see Figure T.71).

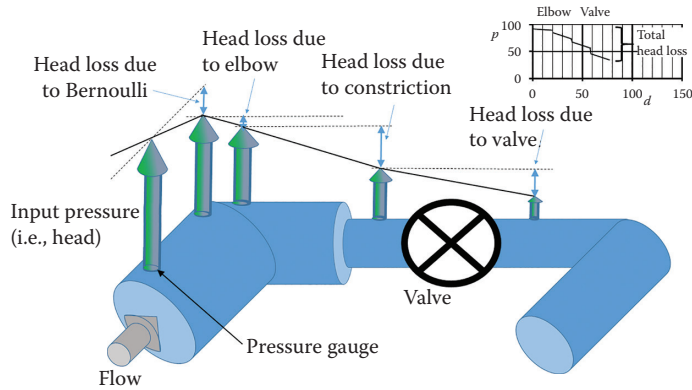


Figure T.71 Total loss for a pipe flow system.

Total lung capacity (TLC)

[biomedical, fluid dynamics] The total volume of GAS filling the lungs at completion of a maximum inspiration. Total lung capacity and other TIDAL BREATHING parameters can be measured with a spirometer. (see RESPIRATION) (see Figure T.72).

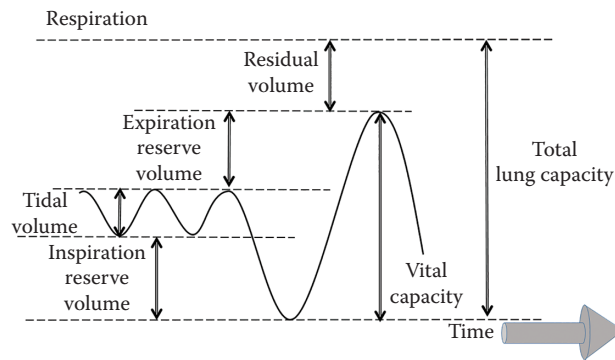


Figure T.72 Diagram illustrating total lung capacity.

Total potential

[thermodynamics] The total potential of a system $\mu = \mu_0 + RT \ln(\rho RT / M p_0) - (1/2)\epsilon^2 [\alpha + (d^2/3kT)]$, where ϵ is the MAGNITUDE of a uniform ELECTROSTATIC FIELD (for instance in a CAPACITOR $\epsilon = \epsilon Q / A$ [ϵ is the DIELECTRIC permittivity, Q the total charge on the capacitor plates, and A is the area of the capacitor]), k is the Boltzmann constant, d the ELECTRIC DIPOLE MOMENT of the respective molecules in the volume, ρ the density, M the MOLECULAR WEIGHT, α the molecular POLARIZATION, and p_0 , μ_0 are constants, with $R = 8.314462175 \text{ J/Kmol}$ the universal gas constant. Similarly the total potential for the individual contributions by the electrons (sub_e), ions (sub_i), and atoms (sub_a) are given by the following respective expressions: $\mu_e = kT \ln[b^3 \rho_e(x) / g_e (2\pi m_e kT)^{3/2}] + \epsilon_0 \epsilon - q_e \psi(x)$; $\mu_i = kT \ln[b^3 \rho_i(x) / g_i (2\pi m_i kT)^{3/2}] + \epsilon_0 \epsilon - q_i \psi(x)$; and $\mu_a = kT \ln[b^3 \rho_a(x) / g_a (2\pi m_a kT)^{3/2}] + \epsilon_0 \epsilon$, where $\psi(x)$ is the electrostatic potential at position x .

Townes, Charles Hard (1915–)

[optics, solid-state] Physicist from the United States. Charles Townes worked on quantum ELECTRONICS principles and microwave ENERGY configuration, with a particular focus on radar applications. In 1964, Charles Townes received the Nobel Prize in Physics for his work on the MASER (microwave amplification by stimulated emission of radiation) with respect to the work published in 1954, the prelude to his participation in the development of the LASER. He shared the Nobel Prize with Nicolay G. Basov (1922–2001) and Aleksandr M. Prokhorov (1916–2002) (see [Figure T.73](#)).



Figure T.73 Charles Hard Townes (1915–).

Townsend, John Sealy Edward, Sir (1868–1957)

[atomic, nuclear] Mathematical physicist from Ireland. Townsend was a contemporary of ERNEST RUTHERFORD (1871–1937) at Cambridge University. In 1897, John Townsend conceived a method to measure the electrical charge, specifically the charge quota contained on an OIL drop in various amounts, hence deriving the QUANTUM effect and determining the single electron charge. This mechanism was later

perfected by ROBERT ANDREWS MILLIKAN (1868–1953). Additional work was in the WAVE theory for electrons and the general QUANTUM THEORY (see Figure T.74).



Figure T.74 Sir John Sealy Edward Townsend (1868–1957). (Courtesy of Biographical Memoirs of Fellows of the Royal Society 1957; JSTOR.)

Trace

[computational] In matrix theory, the sum of the ELEMENTS on the diagonal of an $n \times n$ matrix:

$$\begin{bmatrix} m_{11} & \cdots & m_{1n} \\ \vdots & m_{ii} & \vdots \\ m_{n1} & \cdots & m_{nn} \end{bmatrix}.$$

Tracers

[atomic, biomedical, fluid dynamics, geophysics, meteorology, nuclear] Chemically reactive agents and radioactive isotopes used for identification of metabolic and physiologic processes in specific anatomical locations. Additionally, tracers are used in FLUID DYNAMICS for flow pattern recognition; dyes. The iodine ISOTOPE is used in diagnostic modalities of the thyroid gland, based on gamma RADIATION emission from the iodine, by means of a gamma CAMERA. In the diagnosis of metabolic processes, the use of ¹⁸fluorine in POSITRON EMISSION TOMOGRAPHY (PET) provides insights into the GLUCOSE uptake and cellular consumption as integrated in 2-deoxy-2-(18F)fluoro-D-glucose. Other tracers used in PET imaging are ¹¹carbon, ¹³nitrogen, and ¹⁵oxygen. Histochemical tracers are used for analysis of chemical communications in the synopsis of neural connections. This type of tracer often consists of enzymes and is brought out by staining a biopsy sample. TRACER is an acronym for transition radiation array for cosmic energetic radiation, which is used in atmospheric analysis to gauge cosmic ray MAGNITUDE by means of sensor arrays attached to balloons.

Transcytosis

[biomedical, mechanics] Process under the active process of cellular ingestion of ENDOCYTOSIS, in this case the assimilation of large molecules such as ALBUMIN by means of the invagination process of the CELL MEMBRANE. The forming enclosure produces a vesicle that transports the package to the intercellular content where the vesicle detaches from the cell-membrane lining and subsequently the vesicle disintegrates to release the content for cellular integration.

Transducer

[acoustics, electronics, general, mechanics] Device with a specific transfer function, converting the **MAGNITUDE** of one phenomenon into another. The transfer function consists of a predetermined mathematical relationship that will prescribe a **PROBABILITY** distribution of the output. The translation of the magnitude of one physical quantity into another generally has a predictable response in order to preserve the integrity of the imbedded information. Transducers can function linearly or obey a square law response, or logarithmic/exponential behavior, generally smooth without discontinuities in the range of operations of interest. Transducers are used to convey information on electrical signal strength, temperature, acoustics, optics, as well as **MAGNETIC** and electric field strength next to a range of particles for **RADIOACTIVE DECAY** and elementary **PARTICLE** detection. The majority of devices have an electrical **SIGNAL** as output or for instance for acoustic probes as both input and output (piezoelectric). The most widely used is the **SOUND** transducer as a **MICROPHONE** and a “**SPEAKER**.” Inductive transducers are used as pick-up **ELEMENTS** for electric guitars. Photocells measure **LIGHT** radiance as well as respond to the remote control actuator.

Transformer

[electromagnetism, electronics, general] Electric device operating on the basis of the Faraday induction law. The transformer consists of two parts. An electrical potential applied to the primary winding produces a current that results in a **MAGNETIC FIELD** that is proportional to the number of windings. The magnetic field is captured in a **METAL CORE** that conveys it to a secondary coil. In the secondary coil, the magnetic field induces a current with associated electrical potential, where the electrical potential **MAGNITUDE** (V) is proportional to the number of windings (N). The conversion of the input to the output voltage ratio is directly proportional to the ratio of windings in the primary versus the secondary coil ($V_1/V_2 = (N_1/N_2)$) (see [Figure T.75](#)).

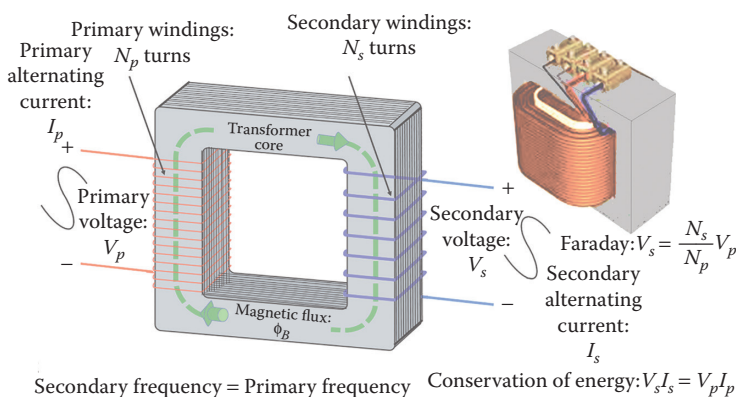


Figure T.75 Diagram outlining the mechanism of action for the transformer.

Transient equilibrium

[nuclear] Equilibrium that is reached through a mediator stage. In nuclear science, the transient state is accomplished through a parent daughter transition where the half-life of **DECAY** for the daughter is shorter than the parent but not intrinsically negligible. The transient equilibrium in **RADIOACTIVE DECAY** is represented by the Bateman equation, linking the parent decay half-life time (τ_p) to the daughter decay half-life time (τ_d) by the definition of the **ACTIVITY** of parent ($A_p = \lambda_p N_p$; $dN_p/dt = -\lambda_p N_p$, λ_p the decay constant of the parent) and offspring ($A_d = \lambda_d N_d$; $dN_d/dt = -\lambda_d N_d$) respectively, captured as $A_d/A_p = \tau_p/(\tau_p - \tau_d)$ BR, where BR is the branching ratio (ratio of decaying particles under a specific process of decay to the total number of decaying particles). The Bateman equation defines the activity

of the daughter as $\mathcal{A}_d = \text{BR} \{ \mathcal{A}_p(0) [\lambda_d / (\lambda_d - \lambda_p)] [e^{-\lambda_p t} - e^{-\lambda_d t}] \} + \mathcal{A}_d(0) e^{-\lambda_d t}$. The time of maximum activity ($t_{\max}$) for the daughter activity in transient equilibrium has an inherent maximum defined as $t_{\max} = 1.44 [\tau_d \tau_p / (\tau_p - \tau_d)] \ln(\tau_p / \tau_d)$, which may exceed the parent activity under certain conditions, in which case there will be *no* EQUILIBRIUM STATE.

Transistor

[atomic, electronics, general, nuclear] Electronic device made from semiconductor materials, or a VACUUM tube that can provide a special electronic function. By means of connecting resistors, capacitors, or inductors to the poles of a transistor, the function can be designed to provide SIGNAL amplification, integration, or differentiation. The specific integration of the transistor in circuits can provide an operational amplifier (also known as INTEGRATED CIRCUITS: IC). The general transistor design consists of two. The semiconductor construction can be npn or pnp. The “n” represents a semiconductor with a donor impurity, doped with electrons, providing a rise in the FERMÍ LEVEL for the ENERGY structure. A P-TYPE SEMICONDUCTOR has an ACCEPTOR IMPURITY that creates a “shortage” of electron, rather represents “holes” with an inherent lowering of the Fermi level. Joining the *p*- and *n*-type media provides a preferred electron migration as is seems for the DIODE. In the transistor, there are three regions of impurities, two of similar nature separated by the complementary energy structure. The material that is sandwiched between the two identical media can have its energy structure manipulated under the influence of an external electrical potential, referred to as the base. The other constituents are the emitter and the collector. The applied electrical potential on the base of the transistor can raise or lower the Fermi level that will accommodate the transport of electrons between the emitter and the collector. Note that the collector “accepts” current, which relates to the emission of electrons; current running from the external power supply’s positive to negative terminal through any electronic device. The construction of the semiconductor layers generally allows for only very thin segment reserved for the “base,” which provides a limited constraint for the electron migration between the emitter and collector only. The base thickness is directly affected by the DRIFT VELOCITY for the electrons; hence, a small thickness yields minimal RESISTANCE. The moment the electrons penetrate the collector volume they have passed the junction that holds a POTENTIAL BARRIER; thus, back DIFFUSION is deemed impossible. Transistors form an essential component in electronic design, using the RESISTOR, CAPACITOR, and INDUCTOR as a means to perform a specific task. Recently a new class of transistors has been introduced: organic luminescent transistors (see PNP-TRANSISTOR, NPN-TRANSISTOR, OPERATIONAL AMPLIFIER, PN-JUNCTION, and DIODE) (see Figure T.76).

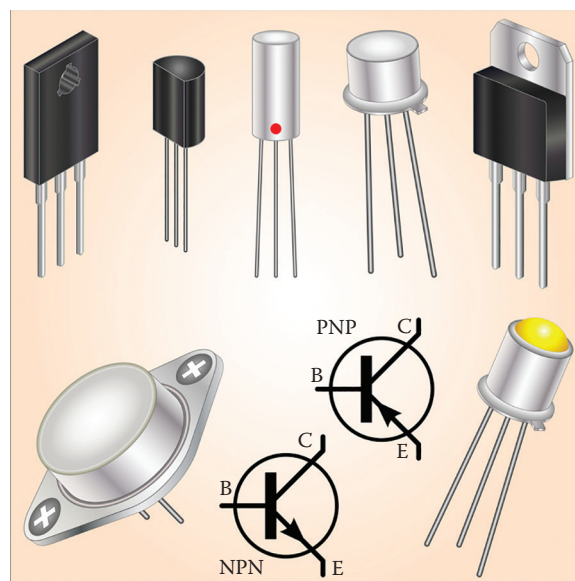


Figure T.76 Classic transistor design, before surface mount miniaturization.

Transmission electron microscope

[biomedical, imaging, nuclear, solid-state] **ELECTRON MICROSCOPE** that measures the transmitted intensity of electrons as a function of location to form an **IMAGE**. The electron microscope was a major implication of the discovery of the electron by **JOSEPH JOHN THOMSON** (1856–1940) in 1897. **HEINRICH HERTZ** (1857–1894) was one of the first who realized that **CATHODE RAYS** were a form of **WAVE MOTION**. Electrons are still generated as a result of a thermoelectric event: thermionic electron gun. In 1899, both the French physicist Alfred-Marie Liénard (1869–1958) and the German scientist Emil Johann Wiechert (1861–1928) independently performed the first mechanism of action to concentrate the cathode rays by means of an axial **MAGNETIC FIELD** produced by a long **SOLENOID**. Hans Busch (1884–1973) provided the theoretical evidence of electron focusing in 1926 (German pioneer in electron optics). In 1931, two German engineers Ernst Ruska (1906–1988) and Maximillion Knoll (1897–1969) performed the first magnification of an electron image. In 1933, Ernst Ruska built the first prototype electron microscope, which was perfected in 1938 by Eli Franklin Burton (1879–1948) in collaboration with his graduate students Cecil Edwin Hall (1912–1991), James Hillier (1915–2007), and Albert Prebus (1931–2000). The transmission microscope, as the word indicates, uses an electron beam, operating at the **DE BROGLIE WAVELENGTH** (**LOUIS VICTOR PIERRE RAYMOND DUC DE BROGLIE** (1892–1987), French physicist postulated the **WAVE** theory of matter in 1924), with the collection of electrons as a function of location on the opposite side of a sample. An electron beam is steered through the manipulation of magnetic fields (**STEM**: scanning transmission electron microscopy). Since the interrogation is performed by means of ballistic electrons, the in-path attenuation must be kept to a minimum; hence, the imaging needs to be performed under mid to high **VACUUM** conditions ($< 10^{-3}$ torr = 0.133 pa). The probing beam is on average 0.5–1 μm in diameter. The resolution (D_r) for the wavelength (λ) associated with the electron trajectory can be defined including an aberration correction with respect to spherical distortions due to the objective's magnetic field (C_s) as $D_r = AC_s^{1/4}\lambda^{3/4}$, where $0.43 < A < 0.7$ is a device and sample material preparation constant. The **RESOLUTION** ranges from 0.5 nm for an acceleration potential of 20 kV to 0.12 nm for an acceleration potential of 1000 kV ($\lambda = 0.004$ nm) (see **ELECTRON MICROSCOPE**) (see [Figure T.77](#)).

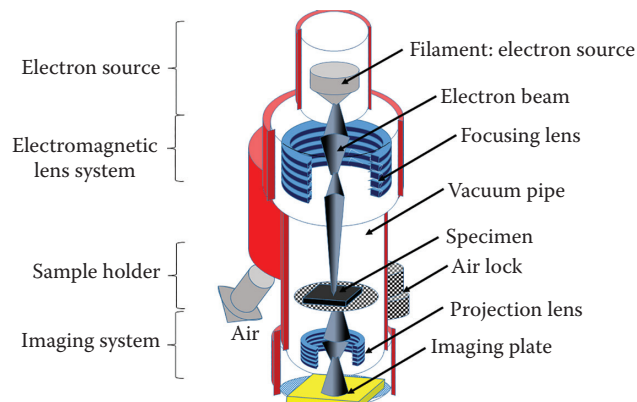


Figure T.77 Transmission electron microscope and operational design and transmission electron imaging representation of neutrophil cells.

Transport equation

[astrophysics/astronomy, fluid dynamics, general, mechanics, optics] Theoretical approach to describe the ordered **MOTION** of particles and photons. The forced migration of particles covers a broad range of phenomena, including but not limited to, the **LIGHT** propagation in tissue under laser irradiation, the **NEUTRON** transport in a **NUCLEAR REACTOR**, the “**DIFFUSION**” of gas and solutes, and the electromagnetic and particle emission for galactic entities (primarily stars). In all cases, the migration process is hindered by

the interaction with substances in the trajectory such as, molecules, ions, dust, uranium-238, and control rods (boron or hafnium or cadmium). The transport equation is a mix of integration and differential operators, accounting for diversion, attenuation, and gain next to source conditions, all as a function of location. Each PARTICLE for a system consisting of a fixed or known number of components (N) has an associated $6N$ first-order differential equations describing the interaction, not accounting for the internal DEGREES OF FREEDOM of the ELEMENTS. The approximation is made that there is consistency for all particles, assuming a PROBABILITY distribution for the spread in parameters associated with the system as a whole. In this case, the transport equation is defined for a single particle. The Transport equation can be considered either as a steady-state problem or as a time-dependent process. The steady-state condition will reduce the complexity on various levels. The introduction of the equation of transfer/transport equation was made by LUDWIG EDUARD BOLTZMANN (1844–1906) in 1872, although he received inspiration/assistance from JAMES CLERK MAXWELL (1831–1879). The formulation adheres to the migration process of a “dilute” GAS MIXTURE with the distribution function $P^{\text{prob}}_i(\vec{r}, \vec{v}_i, t)$ for constituent i at location r in the direction dr , each traveling with velocity v_i at a time t . The interaction probability is indicated by a CROSS SECTION σ_{ij} , with the redirection of the vector captured by $g_{ij}(\theta_i)$, with θ_{ij} the per incidence scattering ANGLE, which is the so-called scattering anisotropy factor or scattering function (also referred to as g-factor). All “particles” are considered to engage a finite volume in space where the items converge from with a solid angle $d\Omega'$ and those will leave the volume after interaction within a solid angle $d\Omega$. The “source” or origin of the particles (photons) is defined through the introduction of a source function $\xi(\vec{r}, \vec{v}_i, t)$. The source can be designed a certain way or follows directly from material properties. A laser beam will be concise and has a Gaussian profile as a function of location (single wavelength; single propagation velocity), whereas a NEUTRON source will be covering full 4π solid angle (for simplicity, one can assume a fixed ENERGY and hence single velocity; and uniform emission angle). The time-dependent formulation is as follows: $(\partial P^{\text{prob}}_i / \partial t) + \vec{v}_i (\partial P^{\text{prob}}_i / \partial \vec{r}) + \xi(\vec{r}, \vec{v}_i, t) (\partial P^{\text{prob}}_i / \partial \vec{v}_i) = \sum_{j=1}^n \iiint \{ P^{\text{prob}}_i P^{\text{prob}'}_j - P^{\text{prob}}_i P^{\text{prob}}_j \} g_{ij}(\theta) \sigma_{ij} d\Omega dv'$, integrated over all space under solid angle Ω . Generally this type of integro differential equation needs to be approximated under certain constrains, or the equation is solved numerically. One approximation is the reduction to a two- or three-flux model, or limit the SCATTERING interaction: only consider isotropic scattering; additionally confining the speed to a single velocity provides a more solvable problem. The transport equation can under limiting constraints be developed in a series that can be truncated under specific boundary conditions. One particular SOLUTION technique using computer simulation is referred to as the MONTE CARLO METHOD, referencing the chance interaction. The Monte Carlo method required defining an appropriate look-up table for the random processes captured by P^{prob}_i , while proposing a single value process for σ_{ij} , and $g_{ij}(\theta_i)$. A special case of the transport equation applies to the fluid-dynamics process of turbulent flow for particles mixtures. For the VELOCITY POTENTIAL of the SOLUTE particles the vorticity is defined as $\vec{\omega} = \nabla \times \vec{v}$. The vorticity transport equation is defined as $D\vec{\omega}/Dt = (\vec{\omega} \cdot \nabla) \vec{v} + \eta_{\text{kin}} \nabla^2 \vec{\omega}$, where $D\vec{\omega}/Dt = \partial \vec{\omega} / \partial t + (\vec{v} \cdot \nabla) \vec{\omega}$, $(\vec{\omega} \cdot \nabla) \vec{v}$ is the “vortex stretching;” the change in particle rotation rate due to velocity gradients, $\vec{v}$ the velocity, $\eta_{\text{kin}} \nabla^2 \vec{\omega}$ describes the diffusion under viscous flow, with η_{kin} the KINEMATIC VISCOSITY that is equal to the diffusion coefficient for diffusion of vorticity. Note that vorticity describes the degree of “rotation” experienced in flow VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$) and TIME (t) expressed as $\vec{\omega}(\vec{r}, t) = \nabla \times \vec{v}(\vec{r}, t)$ (also see EQUATION OF RADIATIVE TRANSFER and TORSIONAL OSCILLATIONS).

Transuranic element

[atomic, nuclear] ELEMENT with atomic number greater than 92 ($Z > 92$; heavy) as listed in the PERIODIC TABLE OF ELEMENTS. Note that $Z = 92$ represents uranium. All elements at $Z > 92$ are radioactive and short lived with lifetime smaller than the AGE of the UNIVERSE as we know it. All currently available transuranic elements have been formed artificially; however, an ISOTOPE of the element plutonium ($Z = 94$) with a half-life of 80 million years has been identified in nature. The lighter transuranic elements ($89 < Z < 103$, full set of 15) is classified as actinides with similar chemical properties to the actinides $57 < Z < 71$. Elements with atomic numbers greater than 100 can only be formed by colliding heavy ions with the atomic number greater than that of helium, forming small quantities, at best several hundred atoms. Based on the formation of the very large nuclei, it has been indicated that $Z = 109$ may be limit of “stable nuclei.”

Although there is a hypothesis that predicts an “island” of nuclear stability in the region $114 < Z < 126$, this remains still to be verified.

Transverse electromagnetic (TEM) waves

[general] Electromagnetic waves in VACUUM are formed by an electric and a MAGNETIC FIELD that are perpendicular to each other as well as to the direction of propagation, which forms the standard definition of electromagnetic RADIATION. However, in CONDUCTOR and semiconductor materials, this may not always hold absolutely true.

Transverse waves

[general] WAVE with the displacement perpendicular to the direction of propagation, for instance a wave on a string or a WATER WAVE; in contrast to a LONGITUDINAL WAVE (compression wave, e.g., SOUND). For a transverse wave, the speed of propagation is a function of the inertial properties of the object in MOTION, the elastic properties of the medium providing the conduction but not the motion of the source. The velocity of propagation (v_w) for a transverse wave on a string is a function of the tension of the string (F_T), and the MASS (m) per unit length (L) with respect to the string itself: $v_w = \sqrt{F_T/(m/L)}$. By changing the tension, the resonant frequency (v_{res}) for the string is altered due to the wavelength (λ) dependency on the tension and the length of the string (ℓ) through $v_{\text{res}} = n(v_w/2\ell)$, $n = 1, 2, 3, \dots$ with the FUNDAMENTAL FREQUENCY for $n = 1$. This involves the tuning of any string instrument. The longest wavelength for a string fixed on both extremes will be one half the wavelength (*also see* COMPRESSION WAVE, ACOUSTICS, and SOUND) (see Figure T.78).



Figure T.78 Transverse wave concept illustrated string plucked generated displacement perpendicular to the direction of motion of propagation, which is along the length of the string.

Traveling salesman problem

[computational] Minimized RANDOM WALK outline. The traveling salesman is trying to configure a route that will allow him to visit each city on his sales list with the shortest time while visiting each city only once and returning to his home. The concept represents determining the optimized process and was introduced in the early 1930s.

Tremor

[acoustics, biomedical, geophysics, mechanics] Structural vibrations, as found in EARTH'S CRUST and buildings and smaller devices. Tremors also describe small EYE movement in the classification of fixation on a point. Other classifications are MICROSACCADE and DRIFT.

Triboelectric sequence

[general] “Tribo” is a Greek word that stands for “FRICTION,” thus referring to the charge transfer between two surfaces as a result of physical contact under MOTION. The triboelectric process provides

the means to transfer charge and generate static ELECTRICITY potential ENERGY resulting from friction. Walking on a polyester carpet is the prime example, specifically under low HUMIDITY. One specific triboelectric phenomenon is the charge separation when clear plastic tape is quickly unwound, maybe using a mechanical rotary axle such as a drill. The charge separation will form arcs that are visible in blue and invisible ULTRAVIOLET. The speed of separation is critical based on the surface conduction leaching off the charge and discharge by means of conduction through the AIR by the lingering humidity. Similar effects may also be observed when spooling a recording tape on older tape-recorder MACHINES (see [Figure T.79](#)).



Figure T.79 Example of the conditions that may lead to triboelectric activity balloon has been rubbed and accumulates static charge.

Triple point

[general, thermodynamics] In a pressure versus temperature PHASE DIAGRAM of a substance there is a point where LIQUID, solid, and gas exist simultaneously. Raising or lowering the temperature or pressure will lead to phase transitions: EVAPORATION, SUBLIMATION and liquification (as well as all the reverse processes). For instance, for water at this point will have the coexistence of liquid water, solid ice, and water vapour (see [Figure T.80](#)).

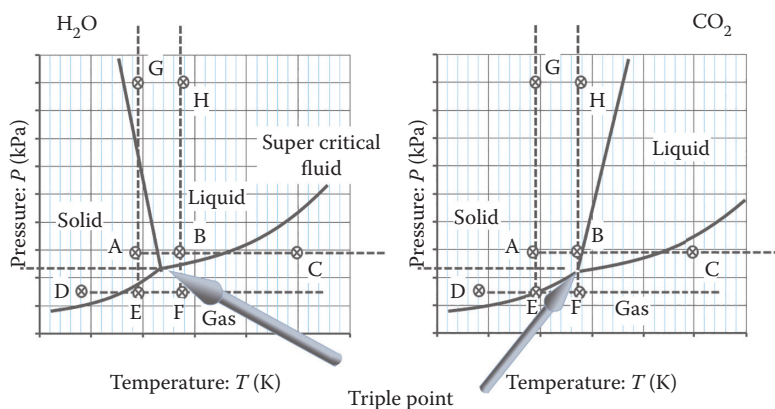


Figure T.80 Triple point, carbon dioxide compared to water.

Triplet, Wild's

[astrophysics/astronomy, geophysics, mechanics, optics] (syn.: galaxy) {use: energy, imaging, origin-of-life (Big Bang)} Wild's triplet GRAVITATION bridge between three galaxies, forming an optimal spatial ANGLE between the respective galaxies (see **WILD'S TRIPLET**).

Triplet state

[atomic, computational, condensed matter, energy, kinetics, nuclear, solid-state] Two coinciding SPIN states for two particles (electron and PROTON) within an atomic structure that result in a spectral HYPERFINE STRUCTURE splitting (spin $S = 1$, quantity $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT), for example, H_2 PROBLEM. This stands in contrast to a SINGLET STATE (spin $S = 0$). In case two electrons converge on a zero angular momentum than the three states are ENERGY degenerate in the values m_s . Singlet oxygen, $\text{O}_2(a^1\Delta_g)$, is the lowest excited electronic state that has been known for molecular oxygen, and has been recognized for at least 80 years. The characteristic chemistry of excited singlet oxygen sets it apart from the triplet GROUND STATE of molecular oxygen, $\text{O}_2(X^3\Sigma^-_g)$. The triplet state can potentially degenerate by PHOSPHORESCENCE. The DEGENERACY for the triplet state can however be removed when an external MAGNETIC FIELD is applied, as described by the ZEEMAN EFFECT (see [Figure T.81](#)).

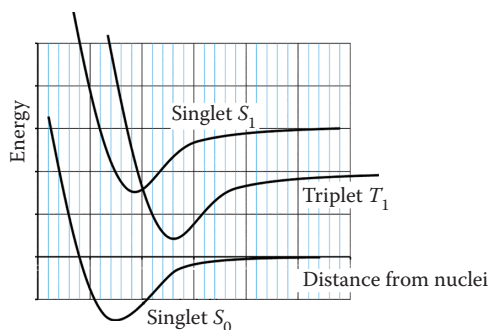


Figure T.81 Triplet state.

Triple-twin domain

[nanotechnology, quantum] {use: elementary particle} Gathering of misplaced ATOM clusters giving rise to local changes in the CRYSTAL STRUCTURE equivalent to the insertion of three nonrelaxed atomic cells. This phenomenon can be described by NUCLEAR FORCES (i.e., the sharing of elementary PARTICLE such as mesons) and van der Waals forces. The van der Waals interaction was discovered by the Dutch scientist JOHANNES DIDERIK VAN DER WAALS (1837–1923). They are the attractive or repulsive forces between molecules and ELEMENTARY PARTICLES that are not the larger scale covalent bonds or due to the ionic electrostatic interaction. The VAN DER WAALS FORCE (also: London–van der Waals) is described by an EQUATION OF STATE of a diluted IDEAL GAS (expressed by the GAS LAW: $P = (N/V)[1 - (aN/VkT)]kT$, where N is Avogadro's number, V and P are the volume and pressure respectively of the "gas," k is the Boltzmann's constant, T the temperature of the "gas," and a the dilution factor) and is related to the Casimir effect for DIELECTRIC media. The phenomenological description assumes interactions between nonzero size particles (i.e., atoms) as a FLUID with a pairwise attraction diminishing roughly according to $1/r^6$, r being the DISTANCE between the pair. Johannes Diderik van der Waals received the

Nobel Prize in Physics in 1910 for his work on the “Equation of state for gases and liquids” published in 1873. The modified IDEAL GAS LAW approximating fluids describing the van der Waals force is given as $F_{\text{vanderWaals}} = (d_1/r^s) - (d_2/r^t)$, where $s \approx 6$ and the second term represents a repulsion with $t \approx 2$ and d_1 and d_2 are size representing constants.

Trochoidal waves

[fluid dynamics] WAVE pattern defined as the curve traced out by a point on a circle as the circle is rolled along a line. The wavelength (λ) of the rolling circle with radius R now becomes $\lambda = 2\pi R$. The wave shape in longitudinal and transverse directions is respectively given as $x = (\lambda/2\pi)\theta - (\lambda/40)\sin\theta$ and $z = (\lambda/40)(1 - \cos\theta)$, where θ represents the ANGLE of rotation of the circle defining the MOTION of the “water molecules.” One notable wave pattern approximation was introduced by William Newell Bascom (1916–2000). In this model, the peak of the wave becomes sharper with increasing AMPLITUDE of higher harmonics. In the Bascom model, the maximum wavelength to wave peak ratio is 7:1, while a peak is not considered a peak if the full angle of the high water level is less than 120° (see [Figure T.82](#)).

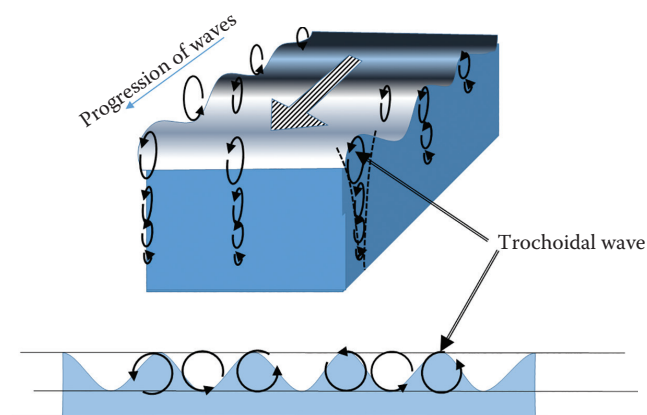


Figure T.82 Trochoidal wave patterns.

Troposphere

[energy, geophysics, thermodynamics] The portion of the Earth’s ATMOSPHERE that we live in, reaching out to approximately 17 km altitude. The troposphere generally consists of the following elementary gasses: nitrogen (on average ~78.09%), oxygen (~20.95%), argon (~0.93%), and carbon dioxide (0.039%) and trace-elements, all as a function of location. Additionally, it holds better than 80% of the earth’s water VAPOR, accounting for various forms of cloud formation, precipitation, and ABSOLUTE HUMIDITY. Pioneers in the study of the earth’s

atmosphere and troposphere are the French scientist and meteorologist Léon Teisserenc de Bort (1855–1933) and the German meteorologist Richard Aßmann (ASSMANN; 1845–1918) (see [Figure T.83](#)).

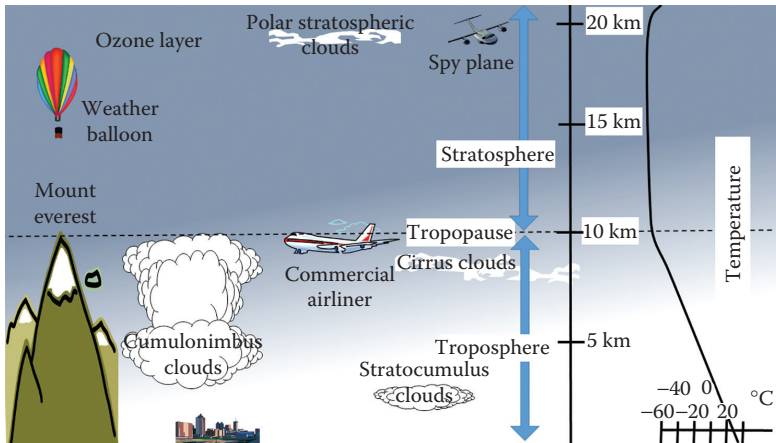


Figure T.83 Troposphere.

Trouton, Frederick Thomas (1863–1922)

[atomic, optics, thermodynamics] Physicist from Ireland. Frederick Trouton performed experimental verification of the earth's AETHER concept; the luminiferous aether (ETHER), the assumed medium required to propagate electromagnetic RADIATION. It was later discovered that the luminiferous aether does not exist; electromagnetic radiation is ENERGY transported through VACUUM as well as AIR and most solids. Trouton's work on THERMODYNAMICS revealed the correlation between the MOLECULAR WEIGHT of substances and the heat of vaporization, known as Trouton's law. Additional work in OPTICS by Frederick Trouton indicated the POLARIZATION interaction on a molecular level, associating the molecular VIBRATION of a substance with the direction of polarization for transmitted LIGHT, also used by EDWIN HERBERT LAND (1909–1991) in 1928, for the polaroid film design (see [Figure T.84](#)).

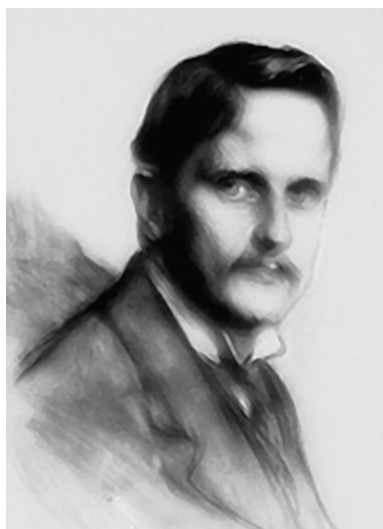


Figure T.84 Frederick Thomas Trouton (1863–1922). (Courtesy of Proceedings of the Royal Society (London), A110, 4, 1926.)

Trouton's rule

[atomic] The entropy of vaporization (ΔS_{vap}) at the boiling point is virtually identical for most LIQUID substances: $\Delta S_{\text{vap}} = 10.5R$, where $R = 8.3144621(75) \text{ J/Kmol}$ is the GAS constant. This rule was expressed in 1884 by FREDERICK TROUTON (1863–1922). With modifications including TEMPERATURE (T) dependence, the validity was extended and is defined as $\Delta S_{\text{vap}} = 4.5R + R \ln T$.

Tsunami

[fluid dynamics, general, geophysics, mechanics] Significant water mass displacement in a WAVE pattern resulting from a sudden perturbation, such as an underwater EARTHQUAKE, volcanic eruption, or landslide, next to for instance a METEOR impact. Tsunamis may be created artificially by explosions as well. In deep water, the tsunami may be composed of a wave pattern over a large surface area with AMPLITUDE of only several CENTIMETERS, but may be as high as several meters. When the wave pattern approached the shallow waters on the shoreline, the wave amplitude may increase dramatically with significant destructive effects due to the sheer MAGNITUDE of the volume of water and the associated force. Due to the deep water at the origin and the large quantity involved, the velocity of the tsunami WATER WAVE can reach excessively high numbers, the wave will slow down as the water depth decreases, potentially in deep water in excess of 200 m/s (see [Figure T.85](#)).



Figure T.85 Tsunami (exaggerated).

Tsvet, Mikhail Semyonovich {Михайл Семёнович Цвет} (1872–1919)

[biomedical, optics] Russian scientist and botanist. Inventor of the concept of CHROMATOGRAPHY, using spectral analysis for identification of biological entities based on molecular optical attenuation information (see Figure T.86).



Figure T.86 Mikhail Semyonovich Tsvet (1872–1919).

Tuft flow

[fluid dynamics] The use of “streamers” to visualize flow patterns. Streamers or tufts are finite length strips attached to a surface of specific contour, placed at regular intervals. Flow can be represented in several different ways in a two-dimensional manner: arrow plots (sometimes referred to as hedgehogs), ribbons, streamlines, line-integral convolution, or streaklines. Arrow plots are an instantaneous representation of the vectors of flow velocity as a function of location. In experimental setting, the use of streamers is used to TRACE the flow. The streamers can be solid material strips or can also be smoke emerging from small orifices spread out over the surface of interest, as well as ink jets. The use of mechanical tufts can indicate streamlines, outlining where the flow field is tangent. Used in the automobile industry for aerodynamic assessment. Also seemingly random WAVE pattern in the grassy leaves on the soil. The grass bends in directions that are compatible with the pressure patterns associated with a turbulent and inhomogeneous wind pattern. The leaning ANGLE and direction of the grass leaves are visual indications of flow stream and to a degree of vorticity. The tuft used for artificial experimental indication of direction and MAGNITUDE resembles the grass leaf, tapering out to the point of attachment. Due to the mechanical structure of the tuft, the full extension of lean provides an indication of magnitude, since the thicker portions at a lower height require a greater force to bend. The physical representation of the bending tuft considers the tuft as a damped bending/flexing strip of variable thickness that obeys Hook’s law: $F_{\text{spring}} = \kappa_i (\ell_{\text{distended}} - \ell_{\text{rest}})$, with κ_i the spring constant and ℓ_i the length. The DAMPING force of the bending spring is proportional to the velocity of movement (proportional to the flow velocity) (ν) and the damping constant (κ_d) expressed as $F_{\text{damping}} = \kappa_d \nu(t)$. The flow will apply an external force (F_{flow}) that provides the sum of forces: $F_{\text{total}} = F_{\text{flow}} + F_{\text{spring}} + F_{\text{damping}}$. Due to the variable “thickness” of the streamer, the streamer (e.g., grass leaf) can for convenience be subdivided in segments with different material properties, with a lower limit of 3 to minimize the complexity of the problem without losing critical information about the flow. Additional segments will add to the computational intricacy. The tip displacement is a direct indication of the flow

velocity (direction and magnitude) and the applied flow force, within certain limits (there will be a maximum force that will LAY the streamer flat on the surface). The SOLUTION process can use either the Euler method or RUNGE–KUTTA METHOD for the integration over the different segments (see Figure T.87).

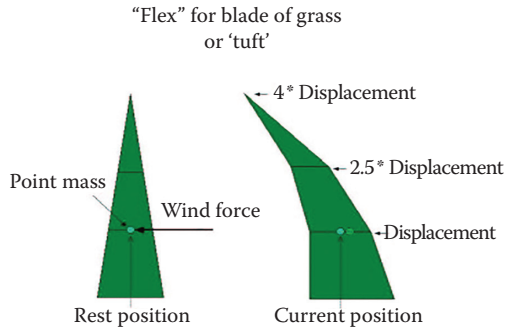


Figure T.87 Tuft flow, plants blown over in various directions due to strong localized wind gusts in random directions for a rice field.

Tungsten filament

[general] “black-body” metal ELEMENT composed form the element tungsten, specifically used in the light-bulb design based on Thomas Alva Edison’s (1847–1931) invention in 1879 that emits LIGHT under the conduction of current (I), while resistive heating of the tungsten wire yields a temperature that provides a COLOR in the yellow/white visible light. The electrical RESISTANCE (R) results in a power conversion (electric to kinetic) of $P = I^2 R$. Resistance generally increases with TEMPERATURE (T) and is generally expressed by the resistivity (ρ_{res} ; $R = \rho_{\text{res}}(L/A)$ for a wire of length (L) and cross-sectional area (A) as $\rho_{\text{res}} = \rho_{\text{res},0}(1 + \alpha_0 \Delta T)$, with α_0 the temperature coefficient of resistivity; a material property (see Figure T.88).



Figure T.88 Tungsten filament.

Tunneling

[nuclear] Also known as TUNNELLING (see QUANTUM TUNNELLING and BARRIER PENETRATION).

Turbine

[energy, fluid dynamics, thermodynamics] Device that under the influence of mechanical MOTION (momentum, force), generally in the format of flow, generates work or specifically ELECTRICITY. The CONSERVATION OF ENERGY law applies and provides the conversion of potential ENERGY to kinetic energy, next to conversion of kinetic energy to work or electric energy (with a loss term as heat, resulting from FRICTION). The mechanism of action for the generation of electrical power relies on rotation combined with a MAGNETIC FIELD, which provides a changing magnetic FLUX captured by a wire loop. The wire-loop magnetic field combination provides an induction, based on the principles of the Faraday induction law. Either a PERMANENT MAGNET is rotating within a wire loop or a wire loop is rotating within a fixed magnetic field. The FLUID flow may be water as in a hydroelectric plant, steam (nuclear power plant, fossil fuel burning power plant), wind as applied to wind-mill generators, piston ENGINE driven axle, and free-running cart with rotating axle as the core of the GENERATOR (turbine). Additional mechanisms are available, such as WAVE MECHANICS where a hinge attached to two plates is changing the ANGLE of attachment under the influence of ocean SURFACE WAVES. The hinge will thus provide an alternating change in captured magnetic flux from the interaction between the “knuckles” of the casing and the axle. An alternative configuration may be by means of a worm-wheel gear system, providing continuous rotation in response to a back-and-forth motion. Wind mills provide several work functions dating back to millennia. The use of wind power to PUMP water out of the GROUND may be the oldest. Wind mills have also been used to pump water from low areas to higher areas to dry out the land for habitation as was done in the north-western part of the Netherlands (north of Amsterdam) in 1533, further institutionalized by the engineer and architect Jan Adriaanszoon Leeghwater (1575–1650) in 1607 (by the way, the last name “Leeghwater” translates as “empty water,” where the original last name was most likely “Adriaanszoon,” but he is known as *Leeghwater*) (see [Figure T.89](#)).

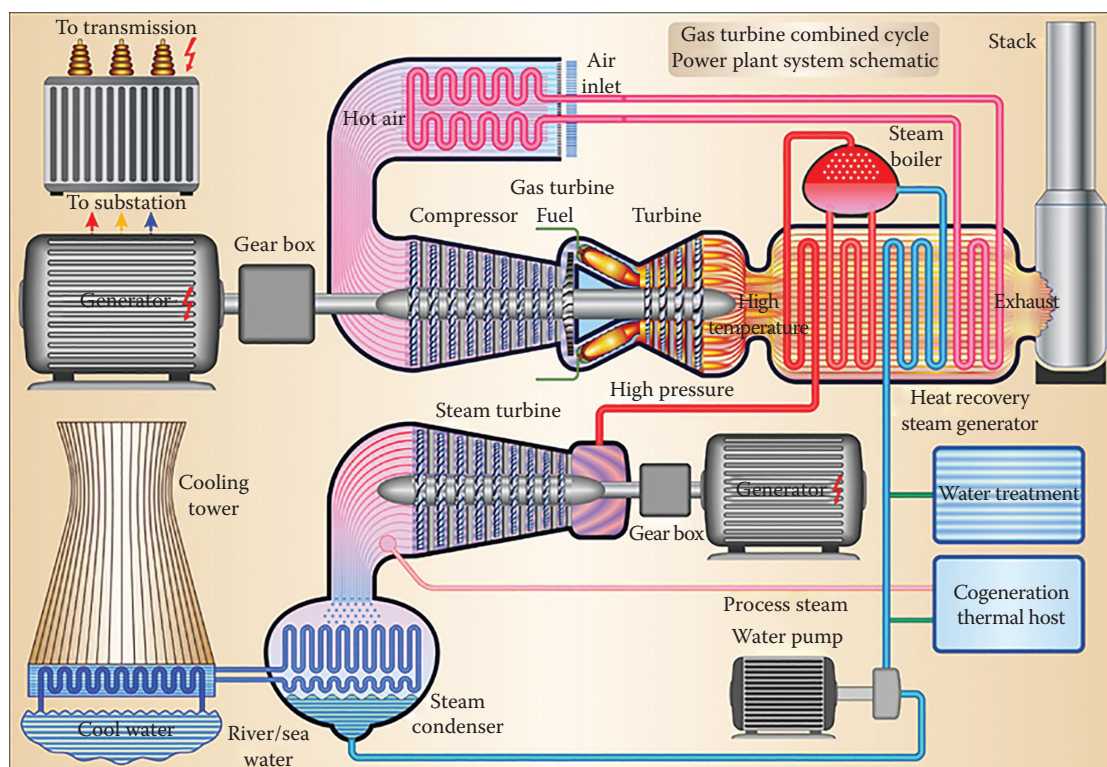


Figure T.89 Schematic of gas turbine.

Turbo machine

[fluid dynamics, mechanics] An assembly of blades, or scoops that require ENERGY to operate (e.g., PUMP) or generate energy (e.g., TURBINE) by means of facilitating flow of a LIQUID through a system of channels, or passages that are configured around an axis of rotation to form a rotor. The turbo mechanism of action either adds energy to the system resulting from an external source of power to operate the system or extracts energy from flow and generates another form of energy, potentially ELECTRICITY (see [Figure T.90](#)).

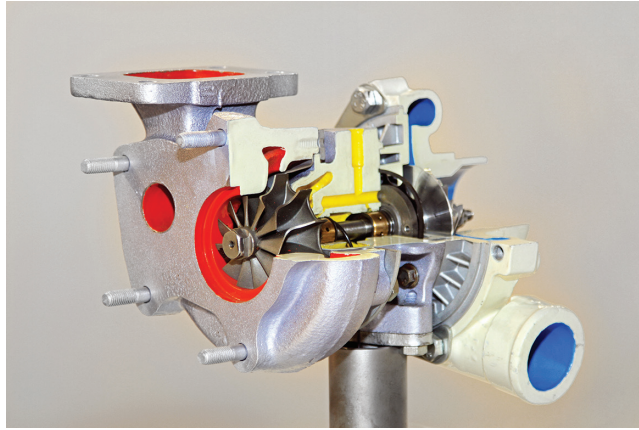


Figure T.90 Turbo charger.

Turboprop engine

[fluid dynamics, mechanics] Combustion TURBINE engine that engages a PROPELLER through a reduction gear. The exhaust gases of the turbine transmit the power from the turbine by means of a shaft to a reduction gear. The use of a down shift in gear is required due to the fact that optimum propeller performance performs at much slower speeds than the revolutions per minute of the turbine. Turboprop engines are a compromise between turbojet engines and mechanical propeller engines (see [Figure T.91](#)).



Figure T.91 Turboprop engine.

Turbulence

[computational, fluid dynamics, geophysics] Fluid flow with a diverse vector spread of flow velocity as a function of location in a three-dimensional space. Turbulent flow will contain vortices, specifically near boundaries that are changing direction with respect to the flow; or obstructions. The potential for developing turbulence is indicated by the **REYNOLDS NUMBER**, which defines the boundary conditions for an incompressible, inviscid viscous flow as a function of flow velocity and interaction range. Under a low Reynolds number, a flow is laminar ($Re < 2000$), while turbulence will be in effect for $Re > 3000$. Turbulence can result from colliding/passing airstreams, as experienced during airplane flight. An associated phenomenon is turbulent **MIXING**, taking place in the **SURFACE BOUNDARY LAYER** with respect to airflow in close proximity to the earth's surface in response to the amalgamated relief patterns as well as colliding airstreams (see [Figure T.92](#)).

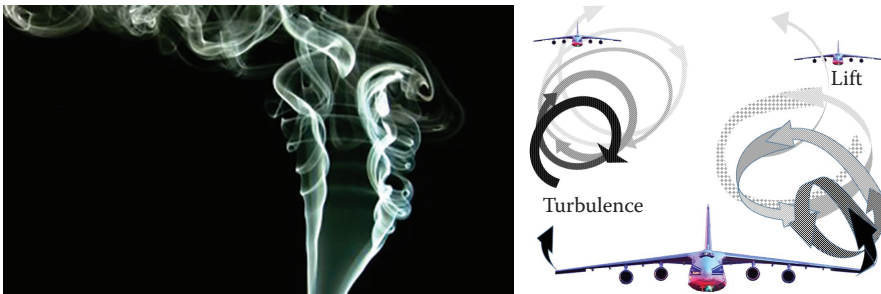


Figure T.92 Turbulent flow.

Twin "paradox"

[general] A popular concept in special relativity is traveling at velocities close to the speed of **LIGHT**. In this case, when two people (twins) are separated based on their profession to perform certain tasks, where one of the twins will have to travel to a distant planetary system at 6 light-years away, while the other twin remains on **EARTH** performing the data communications with the other twin. The spaceship travels at $v = 0.9c$, $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of light. Upon the return the time lapse is $t = (2 \times 6 \text{ light-years}) / 0.9c = 13.3 \text{ years}$. The person remaining on the Earth will have aged 13.3 years, while the person in the spaceship has only aged $\Delta t = 13.3 \text{ years} \cdot \sqrt{1 - (0.9)^2} = 5.8 \text{ years}$. The paradoxical part of this process is that both persons are going to **AGE** at the same rate. The traveling person may return sooner than anticipated (note that at this point the **GENERAL THEORY OF RELATIVITY** has not been considered). The two people may consider themselves at the origin of their own reference frame, traveling with respect to each other. The **INERTIAL REFERENCE FRAME** of the astronaut changes from the same as the twin to the inertial reference frame of the outbound voyage, followed by the inbound voyage (not stopping at the remote location) and returning to the fourth and final inertial reference frame that is the same as the inertial reference frame of the person remaining behind on the Earth. The fact that accelerations are involved for the traveling astronaut, leaving Earth, changing direction on location, and slowing down to land will affect the personal process of time. During the two trips themselves, there is no relativistic interaction. Due to the aspect of acceleration, the general theory of relativity needs to be invoked as well. Integration of all aspects of relativistic **MOTION** results in

a physical changes/differences in AGE, making the traveler arrive back younger (*also see* TIME DILATION, SPECIAL THEORY OF RELATIVITY, *and* GENERAL THEORY OF RELATIVITY (see [Figure T.93](#)).

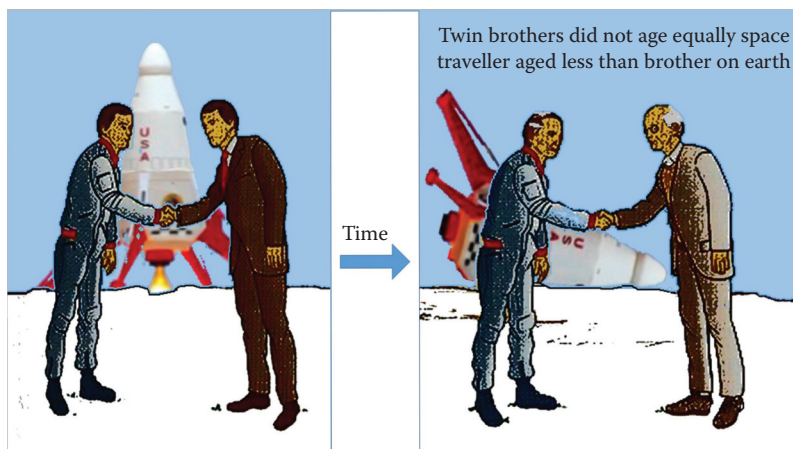


Figure T.93 Twin paradox.

Two-photon absorption

[general, imaging, optics, quantum] Absorption process where two photons are converging on the identical absorbing atomic structure at the exact same time, and, based on the superposition principle, the ENERGY content will have doubled upon interaction, hence providing the exact same effect as the interaction of a single photon with half the wavelength. In this manner, the deeper penetration of long WAVE photons can provide the advantage of deeper penetration and hence avoiding surface effects. The only manner in which the conditions of two-photon absorption can be created is by increasing the PROBABILITY through the release of a massive amount of photons. This large PHOTON quantity corresponds to a high fluence, which can only be achieved under extremely short-pulse duration. Two-photon absorption provides an essential and useful spectroscopic tool.

Two-slit diffraction

[optics] *See* DOUBLE SLIT.

Tyndall, John (1820–1893)

[general, geophysics] Physicist from Ireland. John Tyndall worked on THERMODYNAMICS aspect related to the optical properties of gasses and constructed the first known relative spectrophotometer, measuring the absorption as a function of wavelength in relation to neighboring wavelengths (qualitatively). Based on his observation, Tyndall concluded that the water VAPOR in the Earth's ATMOSPHERE acted as a "blanket" preventing radiative heat loss, thus keeping the surface warm. Tyndall also worked on MAGNETISM and diamagnetic polarity. John Tyndall concluded in 1865 that the emission from a platinum wire heated to 1473 K was approximately 11.7 times more powerful than at 798 K. These experiments were repeated in 1879 by the Austrian scientist JOSEF STEFAN (1835–1893) who derived a generalized statement of emission proportionality with respect to TEMPERATURE (T) to the order T^4 . This was later supported by

LUDWIG EDUARD BOLTZMANN (1844–1906) in 1884 to provide the STEFAN–BOLTZMANN LAW for BLACK-BODY EMISSION as a power function $P = \sigma_{\text{SB}}AT^4$, where $\sigma_{\text{SB}} = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$ the Stefan–Boltzmann coefficient, and A the emissive area (see [Figure T.94](#)).

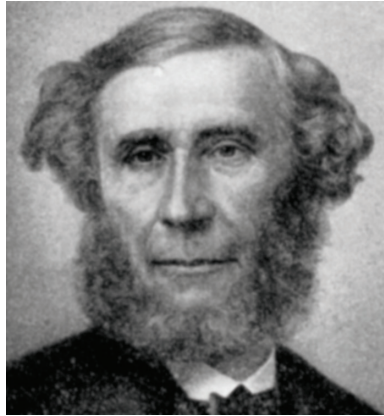


Figure T.94 John Tyndall (1820–1893). (Courtesy of Chandler B. Beach, *The New Student's Reference Work for Teachers Students and Families*, Chicago, IL: F. E. Compton and Company, 1909 the private collection of Roy Winkelman.)



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U-234 ($^{234}_{92}\text{U}$)

[atomic, general, nuclear] Uranium isotope, the least prevalent ISOTOPE of uranium (TRACE).

U-235 ($^{235}_{92}\text{U}$)

[atomic, general, nuclear] Uranium, the second most abundant ISOTOPE of uranium (~0.72%). When a uranium $^{235}_{92}\text{U}$ ATOM is bombarded by a NEUTRON (^1_0n), the FISSION results are as follows: three neutrons, a barium atom ($^{138}_{56}\text{Ba}$), and a krypton atom ($^{95}_{36}\text{Kr}$) (see [Figure U.1](#)).



Figure U.1 Decay process for an unstable uranium isotope.

U-238 ($^{238}_{92}\text{U}$)

[atomic, general, nuclear] Uranium, the most abundant ISOTOPE of uranium ($\sim 99.27\%$) (see URANIUM) (see [Figure U.2](#)).

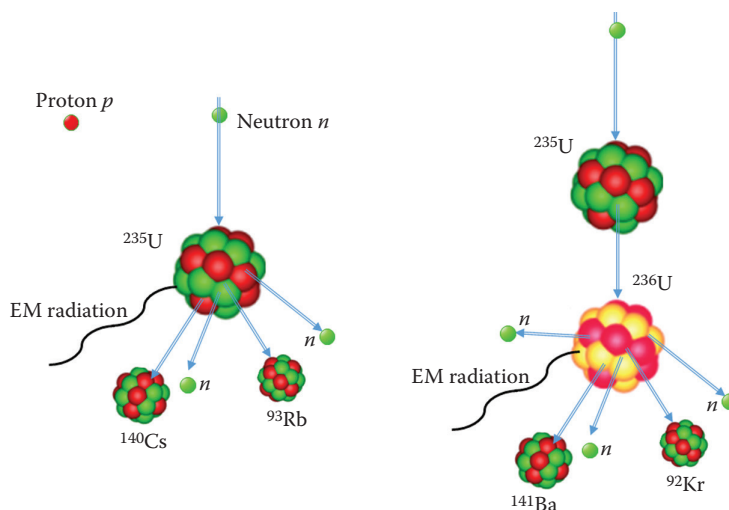


Figure U.2 Illustration of the element uranium.

Uhlenbeck, George Eugene (1900–1988)

[atomic, nuclear] Physicist and chemist from the Netherlands who, in 1925, introduced the concept of ELECTRON SPIN simultaneously but independently from SAMUEL GOUDSMIT (1902–1978) while working under PAUL EHRENFEST (1880–1933), based on the description of the four QUANTUM numbers associated with the electron introduced by WOLFGANG PAULI (1900–1958) (see [Figure U.3](#)).

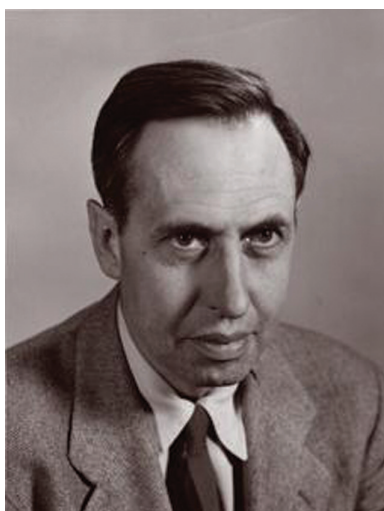


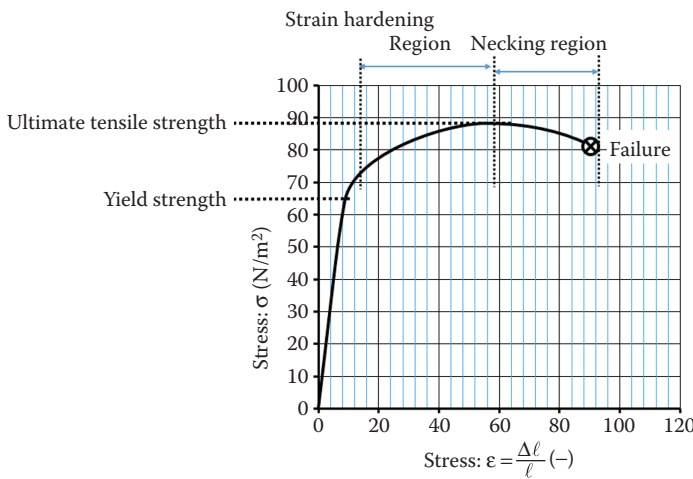
Figure U.3 George Eugene Uhlenbeck (1900–1988).

Ultimate stress

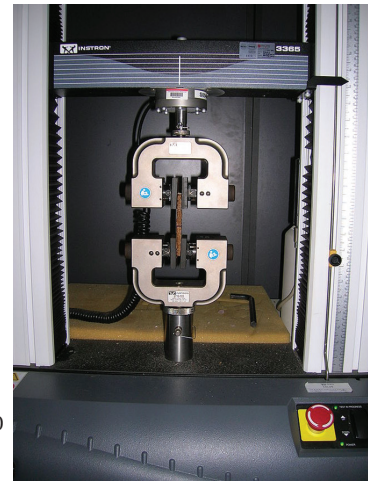
[biomedical, general, mechanics, solid-state] Parameter defining the strength of a material, at this applied stress the material will fail.

Ultimate tensile strength

[general, mechanics, solid-state] Generally strength of a material indicates the ability to resist applied force without failure. The point in the stress–strain curve where the stress starts to decline with increasing strain is the ultimate strength. At the point of the ultimate strength, the material will start to “neck-down” as seen under the stress applied by a device such as an instron, a standard for quality control (see [Figure U.4](#)).



(a)



(b)

Figure U.4 Ultimate tensile strength, fracture under externally applied tension. (a) Graphical representation of the stress curve for a medium until failure and (b) device used to test for yield stress and ultimate tensile strength. (Courtesy of Kerina Yin.)

Ultracentrifuge

[biomedical, mechanics] Rotating device used for molecular analysis. The centrifuge spins vials, ampoules, or test tubes containing SOLVENT with SOLUTES to separate the SOLUTE primarily by weight or size. The functional purposes of the ultracentrifuge can be categorized as follows: (1) determine the VISCOSITY of the solutes and hereby derive the shape and size of the MACROMOLECULES in the SOLUTION, (2) classify constituents on DENSITY, BUOYANCE and density gradient, and (3) characterize the respective MOLECULAR WEIGHTS of dissolved molecules. The specimen containers can be spun at ANGULAR VELOCITIES greater than $120,000 \pi \text{ rad/s}$, which amounts to the radial ACCELERATION equivalent of $260,000g$. Molecular weight can be determined by four different means: SEDIMENT VELOCITY, SEDIMENT EQUILIBRIUM, SEDIMENT EQUILIBRIUM IN A DENSITY GRADIENT, and ARCHIBALD APPROACH TO EQUILIBRIUM METHOD. The segregation and molecular distribution in the container are determined primarily by optical means. The three optical mechanisms that are used are the SCHLIEREN IMAGING for CONCENTRATION, RAYLEIGH SCREENING,

and straight forward OPTICAL ATTENUATION SCREENING. An additional mechanism uses RADIOACTIVE LABELING and counts the RADIOACTIVITY in the sediment with spatial RESOLUTION (see Figure U.5).



Figure U.5 Ultracentrifuge.

Ultrafast biological events

[biomedical, chemical, mechanics, optics] Certain biological phenomena are faster than they might appear. In VISION, it has been shown that in contrast to the slow overall phenomenological mechanism of vision there are events in ROD and CONE sensibility that take place in the femtosecond and even picosecond range. The vision experience itself is however in the 20–100 Hz range with a response time in the order of a few hundredths of a second for the various species. The physiochemical process of the PHOTOCHEMICAL EFFECT in the RETINA is in the same time-scale range as the PHOTOELECTRIC EFFECT for metals. *Also see PHOTOVOLTAICS/ PHOTOELECTRIC EFFECT and SOLAR PANELS*, where the use of biochemical processes generates substantial amounts of electrical potential. Other photobiological processes are at the cellular MEMBRANE level. In the purple bacteria (*Halobacterium halobium*), for instance, light can energize the TRANSMEMBRANE PROTON PUMPING on a femtosecond time scale. In biological cells, there are vibrational mode transitions, specifically in amino-acids, that take place on a femtosecond or shorter scale. Two important spectroscopic phenomena in biological functionality in the ultrashort timeframe are found in PHOTOSYNTHESIS and VISION. The LIGHT interaction in the RODS and CONES of the EYE (receptor protein: rhodopsin, CHROMOPHORE derived from vitamin A) takes place on a femtosecond scale. Rhodopsin is present in both rods and cones for vision. In vision, the QUANTUM states of the excited molecules yield information on the ENERGY transfer. One significant detectable interaction is $C_{11} = C_{12}$ isomerization, which reveals itself through torsional vibrations; specifically the low $C_{12} - H$ VIBRATION frequency in bathorhodopsin that shows anomalous behavior. The first chemical process is

associated with a transition defined by the Frank–Condon state, which has an approximate lifetime of 200 fs (see Figure U.6).

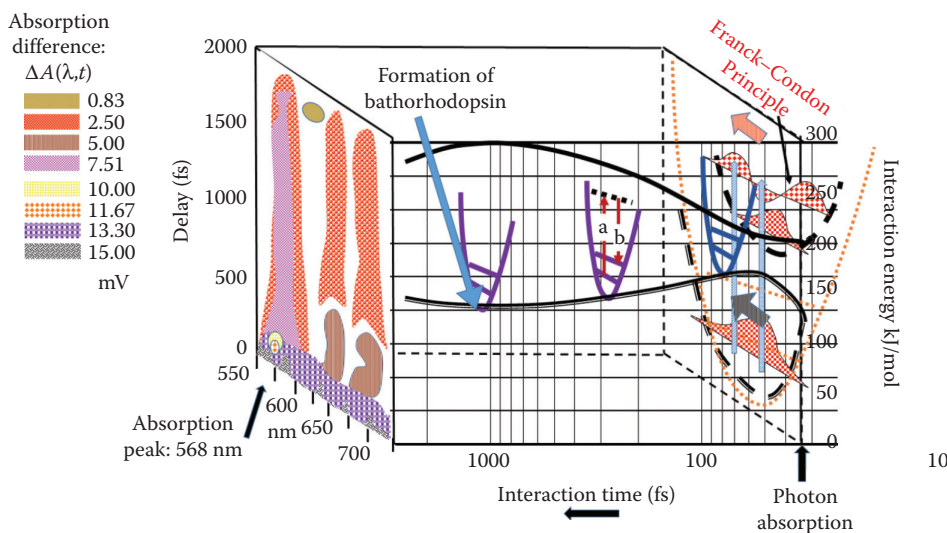


Figure U.6 Ultrafast biological effect. Graphical representation of the chemical response for rhodopsin, transforming into bathorhodopsin. The photon interaction with the associated energy deposition takes place in the first 50 fs of the chemical energy process, depicted on the far right of the graph; indicated by a Franck–Condon event. The spectral information imbedded is shown by the detected Raman emission “a” as well as the detected broadband restructuring fs event with a time-dependent energy profile in the transition “b.” The chemical transformation into bathorhodopsin takes place approximately 1–2 ps into the process. The molecular interaction exemplified by a vibrational process is most pronounced at $\lambda = 568$ nm.

Ultrafast phenomena

[general, solid-state] Ultrashort light pulses can be produced by LASER and more recently light-emitting diodes have accomplished a femtosecond pulse duration. Lasers can operate in MODE-LOCKED MODE, Q-SWITCHED, or COLLIDING PULSE MODE to create femto- and picosecond pulses. Most ultrafast phenomena apply to spectroscopic events, the formation and breakdown of chemical links, either by external excitation (ENERGY source), or in the transition from one state to another (see ULTRAFAST BIOLOGICAL EVENTS and FRANCK–CONDON EFFECT). The phenomenon itself is so fast that the process cannot be observed and can only be derived from related physical conditions and measurements.

Ultrahigh pressure

[atomic, general, geophysics, thermodynamics] The pressure range from 50 to 250 GPa. Under ultrahigh pressure conditions, the PHASE transitions take place on a atomic/molecular LATTICE structure level, for general rocks as well as the formation of diamond. One topic of specific interest is the formation of diamonds from carbon under high temperature and high pressure. Graphite will form into a “diamond” lattice under temperatures ranging from 400°C – 1800°C under respective pressures ranging from 2.5 to 65 Gpa, which can be under normal geological conditions at depths of 150 km and more.

Ultrasonic ablation

[biomedical, mechanics] SOUND waves have ENERGY associated with the time-dependent pressure ($P(t)$) fluctuations (and the associated harmonic changes in the density as a function of time (t): $\rho(t)$) as a function of location based on the INTERNAL ENERGY ($U(t) = (1/\rho)[P(t)/(\gamma - 1)]$, with $\gamma = (1 - [\mu_0/v_s]^2)^{-(1/2)}$, the Lorentz factor, with μ_0 the eddy speed for acoustic propagation and v_s the speed of sound) and the kinetic energy in the direction of interest (which is generally the direction of propagation, which can be in three dimensions) ($KE(t) = \iint (1/2)\rho(\tau)\vec{v}(\tau) \cdot \vec{v}(\tau) d\tau dV'$, for an infinitesimally small volume ELEMENT V' , small enough to be adiabatic and relatively constant). Where the pressure gradient between the crests and troughs provides a mechanism of flow (flow velocity: $\vec{v}(t)$), a potentially rotational flow since the phenomenon can be in a three-dimensional medium (SURFACE WAVES may also have TURBULENCE associated with the WAVE propagation in the three-dimensional medium, but the effects can generally be negligible). Note that the pressure applies a FORCE (F) on the virtual surface, with area A , in the medium of the wave propagation. The total energy provided from the transverse WAVE MOTION in the direction of propagation can be expressed as $\bar{E} \sim A * P' * \overline{v'}|_{\text{direction}}$, for an ISENTROPIC medium ($k_b(\partial T/\partial x_i) = 0$, where T is the temperature and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann coefficient; and $P = \text{Const} * \rho^\gamma$) that is also considered to act as an ideal system (i.e., $\sigma_{ij} = -P\delta_{ij}$, where σ is the local Cauchy stress TENSOR at the plane with “coordinate” i in direction j ; and δ_{ij} the Kronecker delta). This acoustic energy can be applied by focused directional application in the ablation of, for instance, KIDNEY stones, known as lithotripsy. The vibrational energy will intentionally exceed the ULTIMATE TENSILE STRENGTH and the associated shear stress threshold: yield stress of the crystalline aggregate formed from minerals extracted from the digested food products (see Figure U.7).

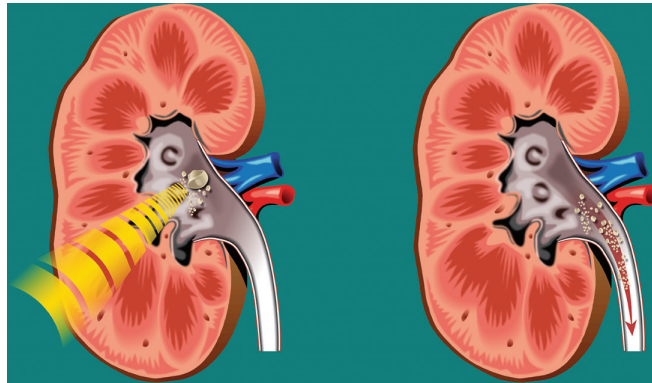


Figure U.7 Ultrasonic ablation; lithotripsy.

Ultrasonic computerized tomography

[acoustics] Imaging process that resembles the mechanism of action for X-RAY computerized TOMOGRAPHY, using pressure WAVE transmission IMAGE formation, and SIGNAL processing based on a line integral of the attenuation on a propagation path. The main difference from ULTRASOUND with X-ray is that the pressure wave PHASE and transmission velocity can be used as a mechanism to localize the mechanical properties of interest at any point along the length of the propagation path of the SOUND wave. The advantage of transmission tomography is the ability to image bulk tissues, not just interfaces, as is generally the case for REFLECTION ultrasound imaging. Hard materials however can significantly block the acoustic transmission, if not at least cause refraction distortions. Some of the density and related Young's modulus information of

the transmission media is also imbedded in the spectral profile of the received signal, which is deconvolved by FOURIER ANALYSIS. Specific material structures, such as fiber structure, can additionally result in DISPERSION that provides material details but also provides distortions if not recognized as such. Ultrasonic computerized tomography is starting to form an alternative to mammography. Note that reflection pulse-echo ULTRASOUND imaging (as used to image for instance a baby in the womb) with an imaging array is also providing a tomographic image reconstruction (see [Figure U.8](#)).



Figure U.8 Three-dimensional reconstruction form of multiple slices of ultrasound scanning arrays. Most well known in the rendering for baby embryo or fetus in the womb. Specifically clear in the comparison between the ultrasound tomography of the baby just prior to birth and a real image captured a few days after birth. Often these images are real time and can display the motions made by the fetus in the womb. In comparison to traditional B-mode ultrasound.

Ultrasonic flow meter

[fluid dynamics] Flow meter based on DOPPLER shift. Designs are available in various shapes and sizes, ranging from a tubular probe that wraps around an artery to a hand-help probe for external flow assessment of a subcutaneous vessels flow (see DOPPLER) (see Figure U.9).

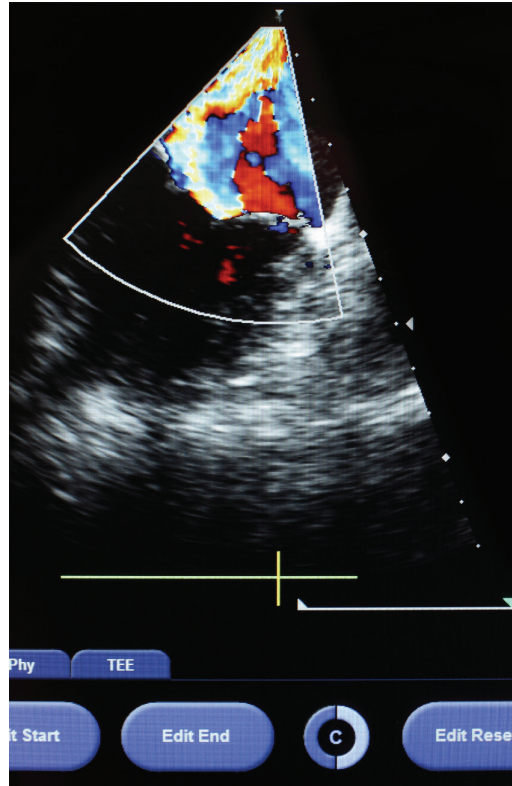


Figure U.9 Ultrasonic flow meter.

Ultrasonic imaging

[biomedical, mechanics] See ULTRASOUND.

Ultrasonic levitation

[general] Lifting an object by means of the force exerted by a JET of FLUID; related to aerodynamic levitation, since SOUND is a pressure wave. The acoustic ENERGY produces a flow of a medium with density ρ , and flow velocity v , that has its roots in the Bernoulli equation and the resulting FORCE (F) is equivalent to the time-averaged gradient in the flow direction ($\hat{x}$) for the kinetic energy density: $F = \partial/\partial\hat{x}(-\rho(v^2/2))$.

The force produced by a standing wave is obviously more powerful than a free-flowing stream. Generally, frequencies in the kHz range are sufficient to produce LEVITATION (see Figure U.10).

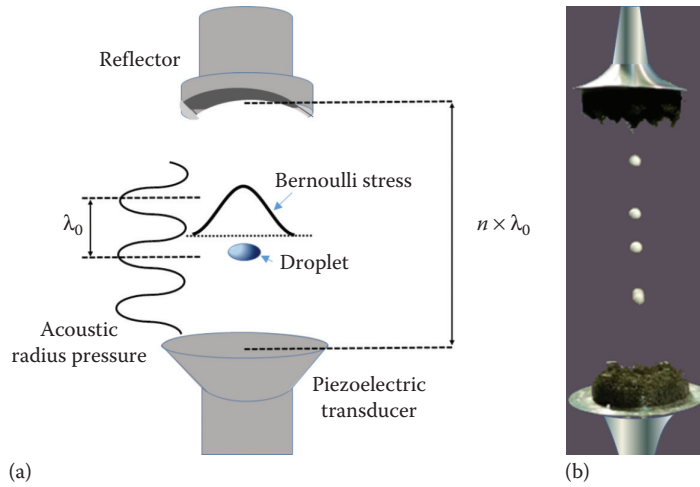


Figure U.10 (a,b) Acoustic levitation. (Courtesy of Mike Szczys.)

Ultrasonics

[acoustics, electronics, mechanics] Using ULTRASOUND; composed of a combination of compressional waves, fast shear waves, and slow shear waves; part of acoustic imaging (*see* ULTRASOUND). Ultrasonics can be used to determine the SHEAR STIFFNESS and SHEAR VISCOSITY of LIQUIDS. Machines using TORSIONAL and SHEAR-WAVE distortions measure the ACOUSTIC RESISTANCE also referred to as ACOUSTIC IMPEDANCE. The acoustic impedance implies that the medium has both elastic and viscous properties. Ultrasonics can be considered a component of nondestructive acoustic testing for flaws in materials. Ultrasonics also refers to the high-frequency probing of animals with reference to their orientation within a volume filled with obstructions as well as recognizing potential targets based on the FREQUENCY SPECTRUM acquired from a back-scattered SOUND, such as the one used by, for instance, bats and dolphins (see Figure U.11).



Figure U.11 Example of ultrasonic nondestructive testing.

Ultrasonograms

[acoustics, biomedical, imaging] Image obtained by ULTRASOUND imaging, primarily in medical diagnostics, also referred to as SONOGRAM.

Ultrasound

[acoustics, biomedical, general, mechanics] Rhythmic pressure disturbances that are beyond the audible range of human detection (range approximately 20–20,000 Hz, depending on the AGE of subject and other factors) for the higher frequencies (ν). Generally ultrasound is considered operating at frequencies of $\nu \geq 20,000$ Hz. The existence of acoustic (pressure-wave) frequencies above 20 kHz was discovered around 1780, but it was not until 1942 that KARL THEODORE DUSSIK (1908–1968), engineer and physician from Austria, used high-frequency pressure WAVE for medical imaging applications. Prior to this, ultrasound was used for detection of flaws in metallic structures in nondestructive quality control. Earlier applications of ultrasound were in echo location, specifically for underwater guidance. REGINALD FESSENDEN (1866–1932) patented the echo-location mechanism of action in 1912. Diagnostic ultrasound relies on the wavelength (λ) for RESOLUTION: $\lambda = \nu/\nu$, with ν being the speed of SOUND in the medium. The smallest items that can be resolved are in the order of half the wavelength in the longitudinal direction when used for imaging. The LATERAL RESOLUTION primarily depends on the acoustic array density (*also see* RAYLEIGH CRITERION and PHASED ARRAY). In diagnostic imaging using ultrasound, the frequency range is generally from 2.0 to 60 MHz. Higher frequencies will have a shallower penetration due to the increased attenuation ($\alpha(\nu)$) according to the relationship $\alpha(\nu) = \beta \nu^n$, where β is a material constant and $1 \leq n \leq 2$ is also a function of the medium in which the compression wave travels. The material constants β and n can be derived from a least square curve fit to the measured attenuation as a function of frequency. Ultrasound is used in biological imaging (e.g., SONOGRAM of fetus), nondestructive testing, and echo location (e.g., submarine navigation, radar as well as navigation used by BATS). In diagnostic use, both MACROSCOPIC and MICROSCOPIC, there are various sources available that can generate longitudinal ultrasonic waves. In medical imaging, the use of anisotropic ferro-electric ceramic crystals has the upper hand, namely piezoelectric transducers (e.g., quartz [one of the initial sources], barium titanate [BaTiO₃], lead zirconate [PbZrO₃], LEAD ZIRCONATE TITANATE [PZT] and lead titanate [PbTiO₃]). Other LONGITUDINAL WAVE sources are lithium niobate (LiNbO₃), lead metaniobate (PbNb₂O₆), zinc oxide (ZnO), polyvinylidene fluoride (PVDF), and Poly(vinyl alcohol) film, PVA. Zinc-oxide can generate frequencies up to 96 GHz. In piezoelectric materials, there is an inherent anisotropy combined with the DIELECTRIC properties of the crystalline structure that will change the crystalline structure under the influence of an external electric field, allowing it to unidirectionally compress under an applied electric potential. The crystalline displacement can be translated to an external medium, causing this medium to compress and expand at the same rate as the crystal subjected to an alternating voltage. The longitudinal pressure wave forms the basis of acoustic imaging or, on a more basic level, DISTANCE gauging. Any vibrating mechanism can produce ultrasonic waves; bats use specialized vocal chords. The acoustic wave traversing the medium will encounter objects that will diffract, scatter, and reflect the wave, in addition to discontinuities in density in general that create acoustic discontinuities in the speed of propagation of sound also known as the acoustic index-of-refraction. Changes in speed of propagation will also obey SNELL'S LAW for ACOUSTICS. High-energy ultrasound can also be used in a destructive mode. Kidney stones are routinely pulverized with the use of intense focused ultrasound, whereas industrial applications include carving and etching of metallics and ceramics and other solids. As a nondestructive testing tool, ultrasonic surface ACOUSTIC WAVES (SAWs) are used to identify anisotropic behavior indicating weaknesses, operating in the GHz range. A similar principle is used for seismologic characterization; in this case the devices are large mechanical tools or even operating under explosive charges.

Other ultrasonic applications are in destructive high-power use from a sonicator, typically operating at 600 W at frequencies around 20 kHz (see [Figure U.12](#)).

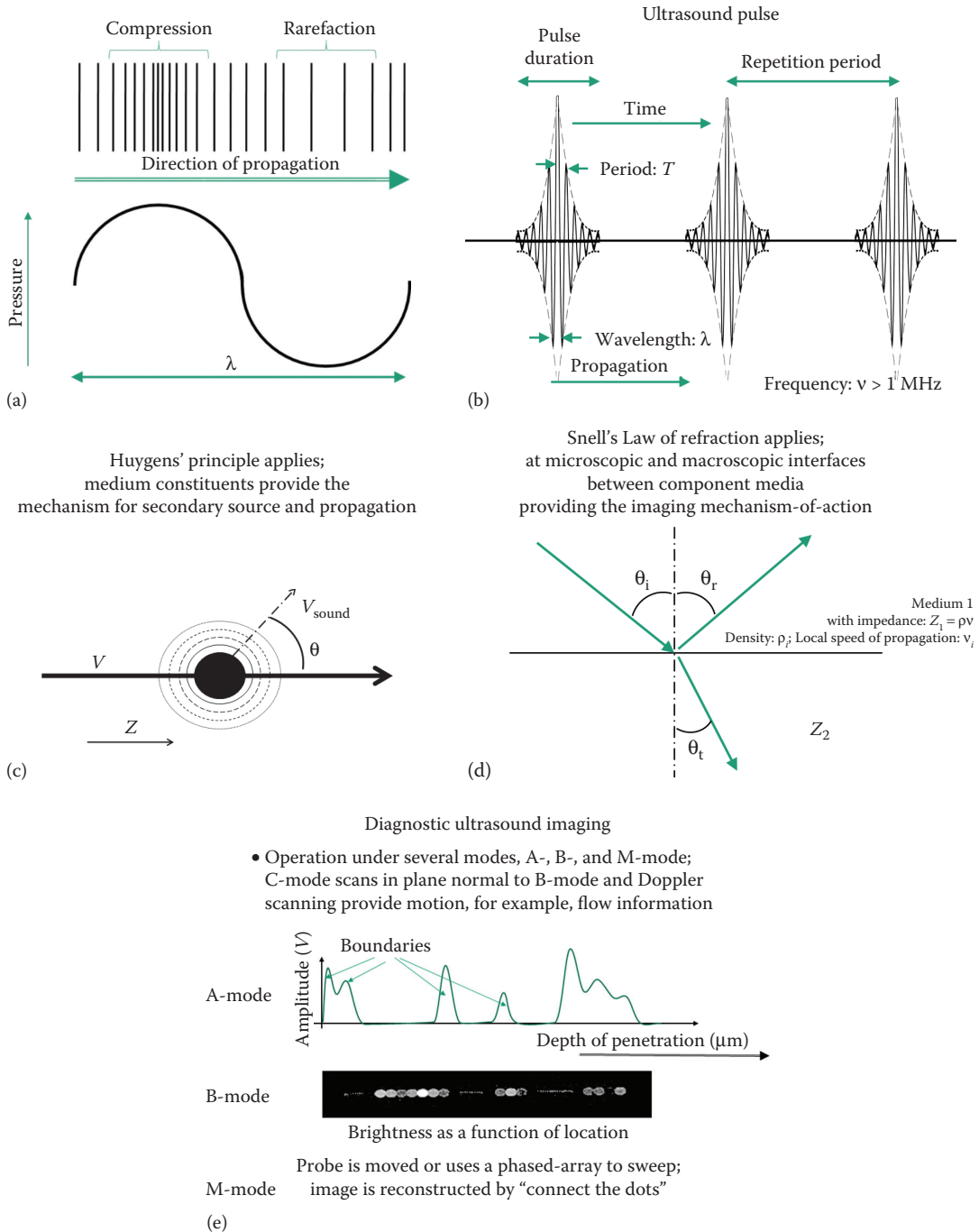
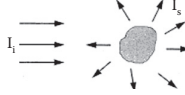


Figure U.12 (a–e) Ultrasound, the clinical term of using acoustic waves to perform noninvasive imaging.

(Continued)

Ultrasound propagation: scatter

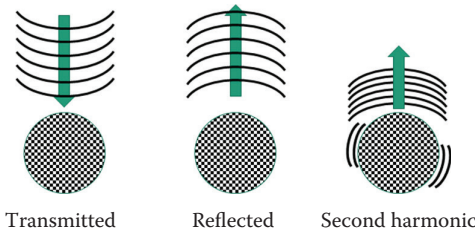
- The scattering cross section: σ_s , which is the power scattered by the object per unit incident intensity, can be solved for a simple sphere with a much smaller dimension than the wavelength as rayleigh scattering



$$\sigma_s = \frac{4\pi}{9} k^4 a^6 \left\{ \left| \frac{G_s}{G} \right|^2 + \frac{1}{3} \left| \frac{3\rho_s - 3\rho}{2\rho_0 + \rho} \right|^2 \right\}$$

(f)

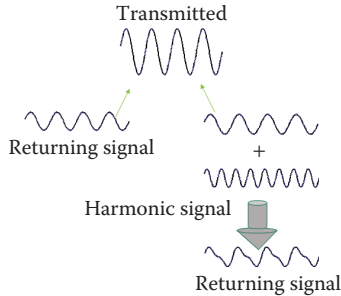
• Harmonic imaging concept



(h) Harmonic wave generation can be facilitated by means of contrast agents

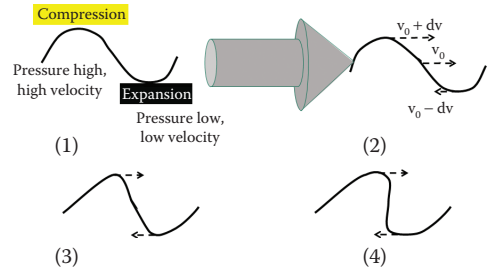
• Harmonic imaging concept

- The returning signal includes not only the fundamental frequency, but also signals of other frequencies.
- The harmonic frequency is twice the fundamental frequency.



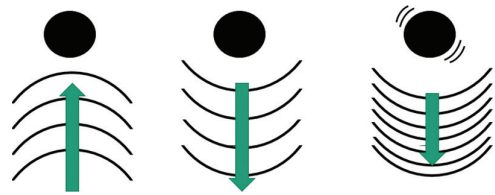
(i)

Acoustic wave-Propagation



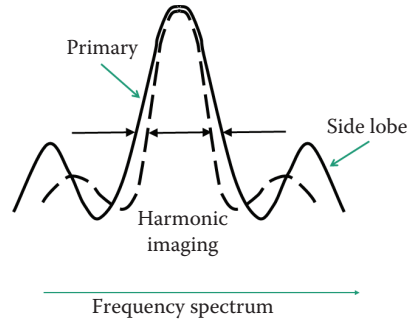
(g) The pressure gradient resulting from the acoustic wave results in local differences in propagation velocity, in turn causing dispersion

• Harmonic imaging concept



Harmonic wave generation can be facilitated by means of contrast agents

• Harmonic imaging concept



(j)

Figure U.12 (Continued) (f–j) Ultrasound, the clinical term of using acoustic waves to perform noninvasive imaging.

Ultraviolet

[optics] Part of the ELECTROMAGNETIC SPECTRUM recognized in 1801–1804 by the Prussian scientist (now Poland) JOHANN WILHELM RITTER (1776–1810) with wavelengths shorter than the visible blue; wavelength range: ~12 to 360 nm. The ultraviolet spectrum is subdivided in three regions, where the extreme ultraviolet (EUV) covers the range: ~12 to 130 nm, and borders X-RAY RADIATION; far ultraviolet covers 130–200 nm; mid UV: 200–300 nm, and near ultraviolet is the spectrum: 300–400 nm. Note that these are approximations and that definitions vary based on the specific field of use or research. Another classification is in the general ranges of ultraviolet, which is more regulated, defining UVC as 100–280 nm; UVB 280–315 nm and UVA in the span 315–400 nm. Ultraviolet in the UVA provides the ENERGY for the CELL to generate vitamin K and changes the chromophores to create a SUN tan. Human VISION ranges roughly from

330 to 660 nm; however, these are not sharp cut-off thresholds. Note that the PERCEPTION has a curve with trailing edges for the CONES on the blue and the RED side, as well as for the “green” cone. Certain animals can see well into the ultraviolet. Most bacteria can be killed by ultraviolet radiation in the range 260–300 nm; wavelengths shorter than 260 nm are even more effective (see [Figure U.13](#)).

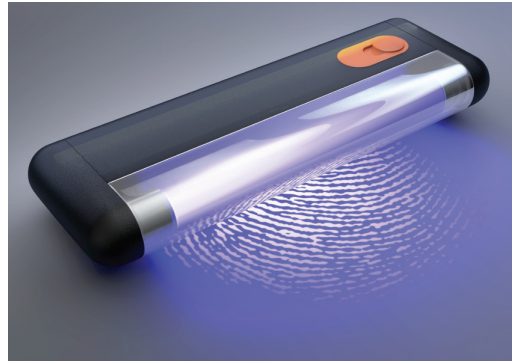


Figure U.13 Ultraviolet, as used in tannin bed. Used in forensics for highlighting chemical components without the direct need for chemical analysis, such as revealing finger print by means of the resident oils.

Ultraviolet catastrophe

[atomic, energy, general, nuclear] The original attempts to model the ENERGY of electromagnetic RADIATION to wavelengths were based on a WAVE theory only, whereas the introduction of QUANTUM MECHANICS applying the energy conversion $E = h\nu = b(c/\lambda)$, with $b = 6.6256 \times 10^{-34}$ Js PLANCK'S CONSTANT, ν the frequency of radiation, $c = 2.997925 \times 10^8$ m/s the speed of LIGHT, and λ the wavelength showed the energy drop in black-body radiation at short wavelengths in contrast to the original EMISSION THEORY as described in the radiation theory introduced by MAX PLANCK (1858–1947). The original radiation theory would allow for an ever increasing energy with a decreasing wavelength emitted under excitation, for instance heat; the ultraviolet catastrophe. Since the original Rayleigh–Jeans theory describes unlimited energy to be generated under limited resources ($E = c\epsilon_B T/\lambda^4$, where $\epsilon_B = 1.38066 \times 10^{-23}$ J/K is the Boltzmann constant, T the temperature), the “catastrophe” was introduced as the energetic conundrum. Experimental observations showed a peak in emission wavelength as a function of temperature, but at shorter wavelengths the emission would drop. QUANTUM THEORY introduced a Boltzmann energy distribution that compensated for the ever increasing WAVE ENERGY with decreasing wavelength (see [Figure U.14](#)).

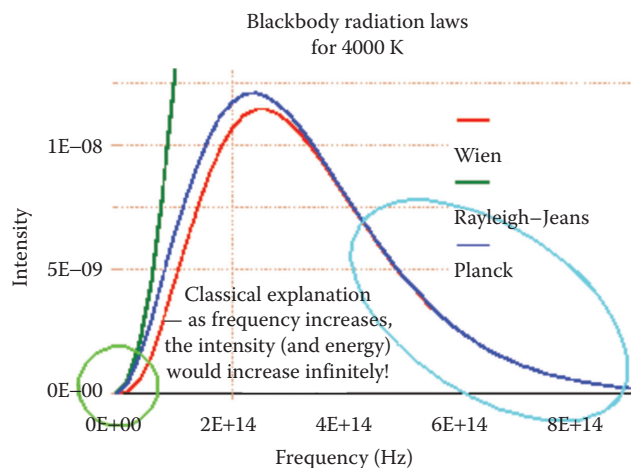


Figure U.14 Ultraviolet catastrophe.

Umbilical cord

[biomedical, chemical, fluid dynamics] Hemodynamic link between the placenta in the mammalian mother and the unborn offspring, containing a variety of stem-cell lines and a BLOOD BARRIER that will not allow different blood types of host and fetus to interact. The umbilical cord provides a means of separation by semipermeable membranes among other mechanisms. There are four different blood group phenotypes: O, A, B, and AB, with rhesus factor either positive or negative (Rh factor). Specifically, since certain blood types cannot mix and will result in instant death for the fetus if no preventative action is taken. Specifically, when the mother is Rh negative and the baby is Rh positive, complications may arise during childbirth if no preventative action is taken. Latin: umbilicus (navel). In aerospace and aviation terms, the umbilical cord refers to the combination fuel-line and control cabling that attaches to a rocket to the main station and is detached on takeoff (see [Figure U.15](#)).

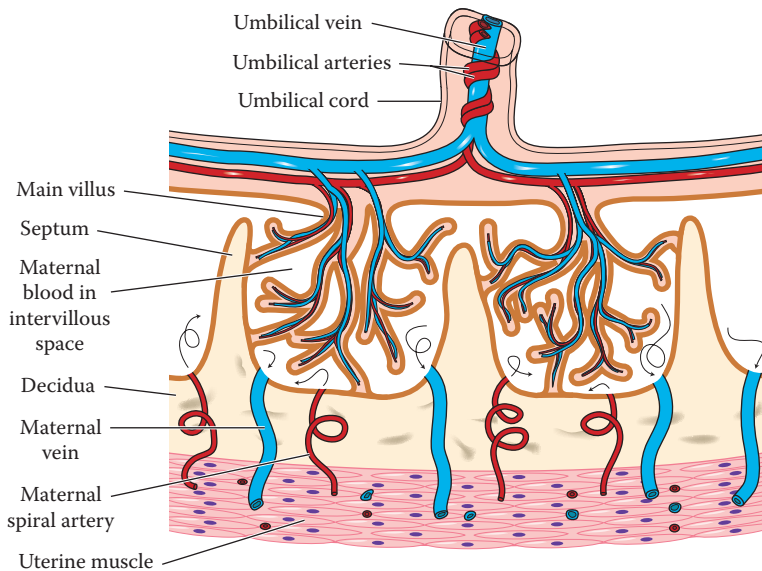


Figure U.15 Umbilical cord, and the chemical exchange through the placenta in the female womb.

Unbestimmtheitsprinzip

[atomic, computational, general, nuclear, solid-state] See **UNCERTAINTY PRINCIPLE**.

Uncertainty principle

[atomic, computational, general, nuclear, solid-state] **QUANTUM** mechanical principle formulated by **WERNER KARL HEISENBERG** (1901–1976). In Heisenberg's words: "UNBESTIMMTHEITSPRINZIP" (German). The uncertainty principle entails that the observation of a phenomenon will influence the phenomenon, more specifically either the location (x) or the momentum (p) can be known, but not both with total accuracy, expressed in one-dimensional analysis as $\Delta p_x \Delta x \geq (1/2)\hbar$, where Δ identifies the uncertainty in the parameter, $\hbar = h/2\pi$, with $h = 4.13567 \times 10^{-15}$ eVs = 7×10^{-34} Js the Planck constant, or referred to by Max Karl Ernst Ludwig Planck (1858–1947) as "the quantum of action." The use of a **PHOTON** to identify a phenomenon or an object will be linked to the photon momentum $p = h/\lambda$. During the probing action, the photon may transfer all of its momentum to the object; however, the resulting momentum of the object will be

uncertain by an amount $\Delta p = h/\lambda$, whereas the location of the object can only be defined as accurate as approximately half a wavelength: $\Delta x \cong \lambda$. The uncertainty principle ties in with QUANTUM MECHANICS due to the fact that the product of the uncertainty in location and momentum (c.q. ENERGY $[E]$): conceptually $\Delta E \Delta x \geq (1/2)\hbar$ is finite and not zero. Under classical mechanics conditions, the speed of LIGHT would yield $c = \infty$ and the constant, at this point undefined, would be $\hbar = 0$. Uncertainty with respect to nuclear electrons; based on the general terms of the uncertainty principle that no electrons can exist inside the NUCLEUS based on the fact that the nucleus has a diameter in the order of $\Delta x = d = 1.0 \times 10^{-14}$ m, providing a kinetic energy $KE = 9.3$ MeV greater than any electron ACTIVITY related phenomena, meaning that the nucleus has too much energy content for an electron. In three-dimensional analysis of a WAVEFUNCTION (ψ), the uncertainty principle can be expressed as $\psi, (\mathbf{p} - \bar{\mathbf{p}})^2 \psi \psi$, and $(\mathbf{x} - \bar{\mathbf{x}})^2 \psi \geq 9\hbar^2/4$, where $\mathbf{p} = -i\hbar\nabla$ is the momentum operator, with $\nabla = \sum_{i=1}^n d/d\xi_i$ the Laplace operator, ξ_i denoting the DEGREES OF FREEDOM, $\mathbf{x}$ the position operator in the ξ space, $\bar{\mathbf{p}} = \psi, \mathbf{p}\psi$ is the average momentum, and $\bar{\mathbf{x}} = \psi, \mathbf{x}\psi$ is the average position. Note the DE BROGLIE WAVE for moving objects still applies. Generally under these conditions, the expected value for an observable parameter (X) (i.e., operator) is expressed as $\psi, X\psi = \int \psi(\mathbf{x})^* X\psi(\mathbf{x}) d^3\xi$ (see Figure U.16).

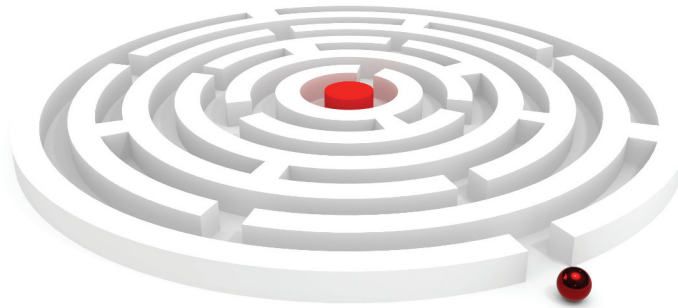


Figure U.16 Graphical illustration of the uncertainty principle: the observation of the location for a phenomenon is obscured by the momentum and associated velocity of the phenomenon. One cannot identify the location of a moving object due to the combined velocity and mass of the phenomena associated with the object.

Uncorrelated states

[thermodynamics] Generally ENERGY has an additive quality, where a system containing two or more subsystems will contain the sum of the energy of both subsystems. This also means that the encompassing system will contain all the states of the subsystems to form a composite system. Keeping this in mind, the states will be interrelated. In certain cases, the environment of the system will have states of its own, when the external states do not influence the internal states, and as such are isolated (and hence autonomous), they are considered uncorrelated. The uncorrelated states are hence impervious to the values of the properties of external systems, which is most often the general assumption in describing a physical phenomenon unless there is a direct exchange with the environment, which would imply that the environment is part of the system and is not a separate system. One rudimentary example is a thermos flask that is being uncorked, which connects the outside system.

Underdamped system

[general] OSCILLATION with a slow decreasing AMPLITUDE after the driving FORCE has been removed. The driving force generates a FORCED OSCILLATION. Even though a true underdamped system would be energetically unsupported, the closest examples are the free oscillation of a gong or a tuning fork. In theory,

the only underdamped system is the PHOTON, where perfect MONOCHROMATIC LIGHT has an infinite wavelength. Compare to CRITICALLY DAMPED, UNDERDAMPED, DAMPED SYSTEM, and OVERDAMPED system (*also see DAMPED OSCILLATION*) (see [Figure U.17](#)).

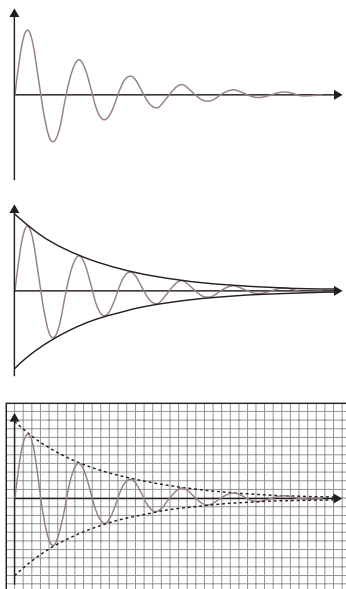


Figure U.17 Underdamped system of the photon, underdamped system of the gong or tuning fork.

Unequal-arm balance

[general] Weighing system that uses a torque as a means of equating the (gravitational) force multiplied by the arm length from an unknown mass against that of a known and calibrated mass and the respective arm length on the balance.

Unified atomic mass units (*u*)

[atomic, general, solid-state] One kilo MOLE of an ELEMENT of choice has a mass in kilogram that is by definition equal to the molecular mass of that element expressed in units *u*.

Unified Fourier reconstruction

[acoustics] Graphic reconstruction from ULTRASOUND data using unevenly spaced data SAMPLING values to shape the outlines of an object/perimeter of a boundary relying on interpolation. The spatial domain FOURIER TRANSFORM is adjusted for discontinuities as such revealing the discontinuities by adaptively spatially limiting the range over which the Fourier transform is composed.

Unified theories of the weak and electromagnetic interactions

[computational, electrodynamics, electromagnetic, general, quantum] Even though weak interactions (very large vector field $W^{//} = C_1 \vec{p}_e \cdot \langle \vec{J} \rangle + C_2$, with $\vec{p}_e$ the momentum vector of the electron distribution and $\vec{J}$ the charge POLARIZATION for the NUCLEUS, C_i constants, which apropos, are nonconservative with respect to PARITY) and electromagnetic interactions (PHOTON) there is a computational analogy between the two mechanisms in vectorial form.

Unified theory

[computational, dynamics, electromagnetism, general, quantum] In the theoretical description of weak and electromagnetic interactions, there are commonalities that transgress the interactions of massless photons versus extensive values for the mass-equivalent weak interactions found in leptons and hadrons. The scale at which this phenomenon gains importance is of the order of 1/1000th the size of a NUCLEUS. The WEAK INTERACTION is described as a weak-interaction density distribution ($\mathcal{L}_W$) with the Lagrangian formulated in vectorial quantities as $\mathcal{L}_W = -(G/\sqrt{2})J_\alpha^\dagger(x)J^\alpha(x)$, where $J^\alpha(x)$ represents the charge current, $J_\alpha^\dagger(x)$ the current equivalence for raising a charge in a transition such as from n state to p state, and G is the gravitational constant (see Figure U.18).

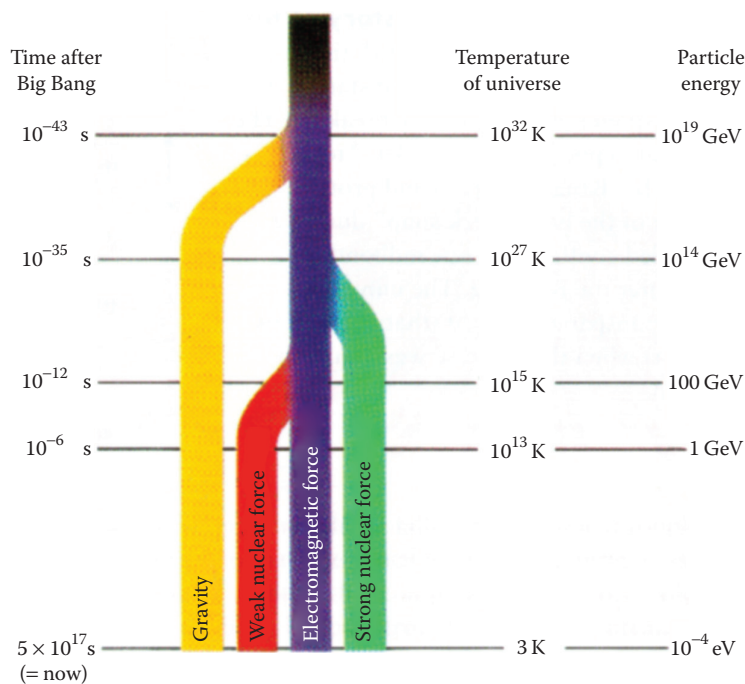


Figure U.18 Unified theory in graphical form. (Courtesy of James N. Imamura, University of Oregon, Eugene, OR.)

Universal gravitation, law of

[astrophysics/astronomy, general] See LAW OF UNIVERSAL GRAVITATION.

Universal gravitational constant (G)

[astrophysics/astronomy, general] Based on SIR ISAAC NEWTON's (1642–1727) deduction that gravitational attraction is directly proportional to the product of the masses (m_i) of the respective objects involved, and inversely proportional to the square of the separating DISTANCE (r), as described in his LAW OF UNIVERSAL GRAVITATION; he introduced a constant that holds true for all planetary gravitational interactions: $F = G(m_1m_2/r^2)$, with the universal gravitational constant $G = 6.6720 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$.

Universe

[astrophysics, general, geophysics] Collection of all galaxies, containing solar systems and meteors and galactic dust resulting in what is currently believed to be the result of an explosion that occurred approximately 1.5×10^9 years ago. Currently, the Universe is consistently expanding supporting this theory, making

certain galaxies move away from us, whereas other galaxies that we move toward seem to gain on us. The knowledge supporting the EXPANDING UNIVERSE is based on data acquired by Hubble, and the Hubble TELESCOPE in outer space. These relative galactic movements can be verified by the red- and BLUE-SHIFT phenomena (regular and relativistic DOPPLER EFFECT). One major dilemma with respect to the “BIG BANG” THEORY is that this seemingly requires the generation of ENERGY out of “nothing” (*also see* **BIG BANG THEORY**) (see [Figure U.19](#)).

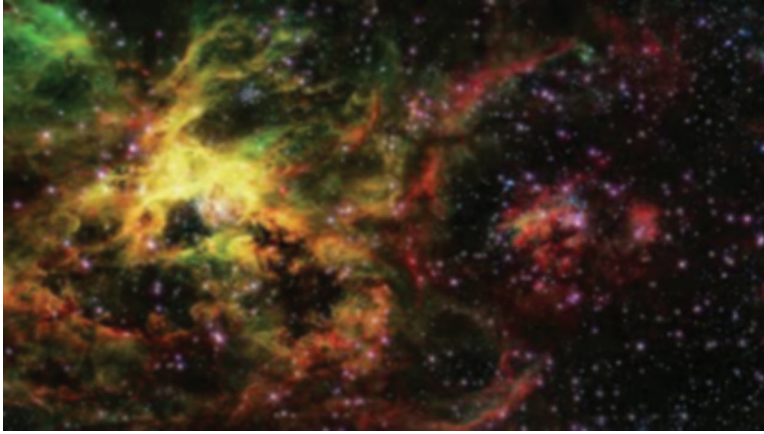


Figure U.19 The universe, artist impression and images acquired by the Hubble Space Telescope.

Unstable equilibrium state

[atomic, geophysics, solid-state, thermodynamics] State of medium that can spontaneously transition into another state, or series of cascading states with associated short-lived interactions. An example of a specific unstable equilibrium would be a supercritical NUCLEAR REACTOR, without NEUTRON. Introducing a single neutron will cause a sequence of events that can generate a substantial amount of ENERGY. Alternatively, an object that is supported above the CENTER OF GRAVITY (center of mass) will be in stable equilibrium, whereas when the object is supported below the center of gravity this will provide an unstable equilibrium (see [Figure U.20](#)).

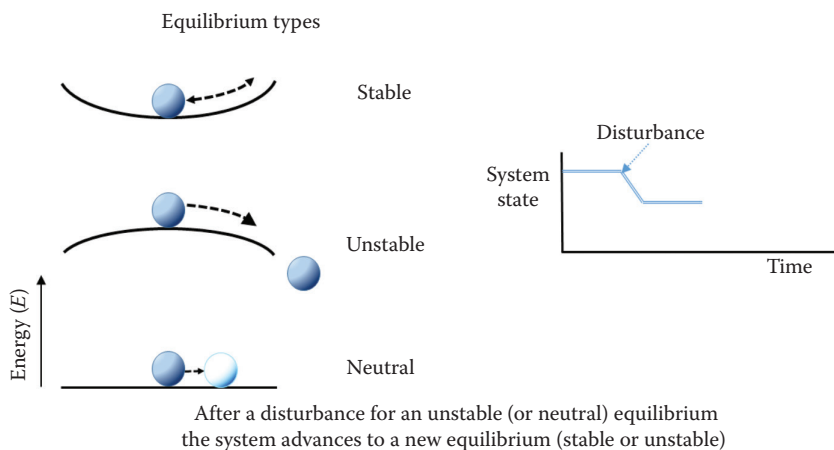


Figure U.20 Energy diagram for an unstable equilibrium state.

Unsteady flow

[fluid dynamics] Flow process that involves discharge at the initial or final segment of the flow process. There are multiple inlet and outlet access routes that add or subtract from the flow process. Unsteady flow is a complex mechanism and requires computational fluid-dynamic analysis (see [Figure U.21](#)).

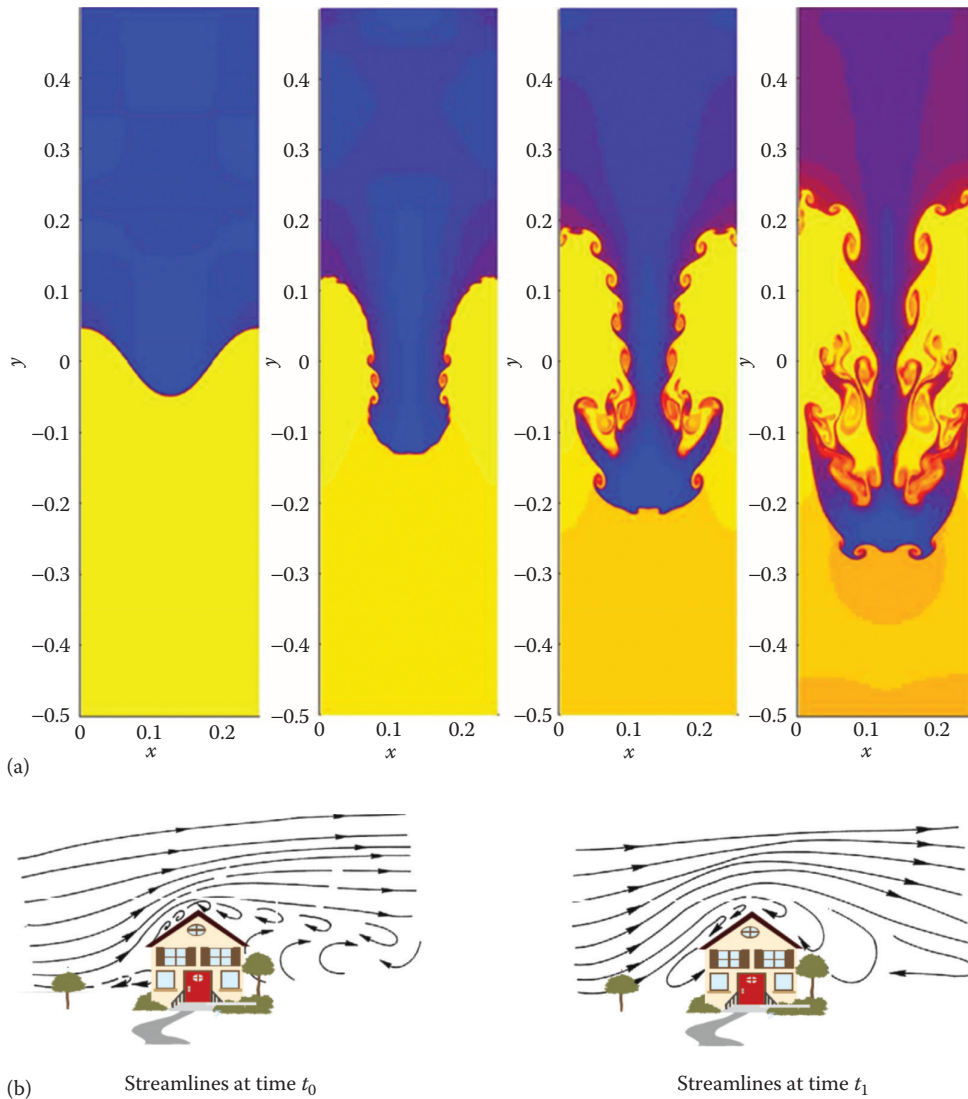


Figure U.21 Flow changing over time, due to the flow developing process based on the boundary conditions as well as the initial conditions or changing flow conditions due to perturbations. (a) Hydrodynamics simulation of the Rayleigh–Taylor instability. (Courtesy Shengtai Li, Hui Li; the U.S. Department of Energy.) (b) Streamlines for flow development with respect to onset of flow (e.g., wind gust).

Unsteady state

[thermodynamics] The state of a medium that changes due to interactions with other systems. One specific example of an unsteady state is the electric charging of a BATTERY; this will proceed until the battery is fully charged.

Up antiquark

[atomic, general, nuclear] Antiquark that has flavor “up” (*also see* UP QUARK).

Up quark

[atomic, general, nuclear] Quark that has FLAVOR “up” (*also see* ELEMENTARY PARTICLE). Quark with the following characteristics: charge: $+(2/3)e$; SPIN: $(1/2)\hbar$; BARYON NUMBER: $1/3$; strangeness: 0; CHARM: 0; bottomness: 0; and topness: 0 (*see* QUARK).

U-quark

[atomic, general, nuclear] *See* UP QUARK.

Uranium ($^{238}_{92}\text{U}$)

[atomic, nuclear] The most prevalent uranium ISOTOPE (99.275%), discovered in 1789. Uranium-238 is a stable isotope with a half-life of 4.5 billion years. Uranium-238 can be made into a FISSION product to generate ENERGY by bombardment with a NEUTRON, with subsequent two beta decays rendering plutonium-239, a nuclear component for fission used in explosive devices. U-238 is also used as a coating for bullets, providing them with armor-piercing capabilities. Also known as depleted uranium, reduced commercial value with respect to the naturally fissile uranium-235 (used in the first ATOMIC BOMB: “Little Boy,” 1945). Uranium 238 is a by-product of the uranium enrichment process of extracting U-235, occurring at ~0.7% in natural state, where U^{235} is fuel for nuclear power plants; at 3%–4% concentration (*see* Figure U.22).

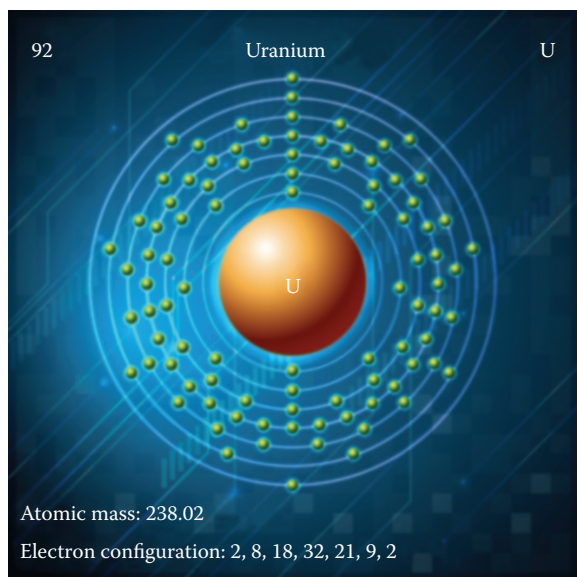


Figure U.22 Uranium, ($^{238}_{92}\text{U}$), electron configuration; McArthur River Uranium Mine; drill core mineralized stable $^{238}_{92}\text{U}$ uranium; uranium ore (uraninite) from Příbram, Czech Republic.

Urey, Harold Clayton (1893–1981)

[atomic, nuclear] Chemist and physicist from the United States who performed pioneering work in ISOTOPE analysis. Harold Urey is best known for his discovery of the deuterium isotope of hydrogen in 1931. Urey received the Nobel Prize in Chemistry for his work in nuclear PHYSICS in 1934, specifically the principal mechanisms of NUCLEAR FUSION. Additional work was in the isolation of various isotopes, including carbon, nitrogen, and sulphur (see [Figure U.23](#)).



Figure U.23 Harold Clayton Urey (1893–1981). (Courtesy of Columbia University, New York.)



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V particles

[atomic, mechanics, nuclear, quantum] Generic name introduced in the 1940s describing unstable subatomic PARTICLE that, when undergoing its principle DECAY mechanism, will produce a pair of particles that are emitted in a v-form when observed in a BUBBLE CHAMBER. Since then these particles have been identified as MESON or BARYON particles (for instance, K-MESON and sigma-baryon) and the term v-particle has not been used anymore, but may still be found in reference material concerning the interaction of COSMIC RAYS with upper atmospheric conditions.

Vacuum

[general] Description of lower limit of pressure. Pressure by definition is the force per unit area for a volume that has an infinitesimal small surface area (A), expressed as $P = \lim_{A \rightarrow 0} (\rho g V / A)$, with the local density ρ , volume V , and GRAVITATIONAL ACCELERATION g . For vacuum $P \downarrow 0$, which means that for a finite volume the density shall approach zero, so that there are no intermolecular collisions possible that could yield a net force. Pressure in general was first measured in 1644 by one of GALILEO GALILEI's (1564–1642) assistants; the Italian scientist EVANGELISTA TORRICELLI (1608–1647) and this was expanded on by the French mathematician BLAISE PASCAL (1623–1662) in 1648, both man have their names associated with the units for the MAGNITUDE of pressure, specifically the “TORR” (1 torr = 1 mmHG; mercury) from Torricelli for low

pressure, and Pascal for ATMOSPHERIC PRESSURE and high pressure. Generally, the Pascal sets the standard for all pressure measures; 1 torr = 133.3 Pa (see Figure V.1).



Figure V.1 Vacuum; examples of conditions and applications of a pressure below atmospheric value. (a) outer space at deep (mm Hg) vacuum conditions, (sealed food with air removed to increase storage shelf-life) CRT scope tube with vacuum to increase electron flow conditions. (b) Suction pad used to attach to flat surfaces in order to facilitate lifting by means of the vacuum device.

Vacuum field equations

[astrophysics/astronomy, computational, optics] Description of gravitational interaction, including GRAVITATIONAL WAVES, and specifically the interaction with electromagnetic RADIATION known as Einstein's field equations under conditions at ABSOLUTE ZERO temperature, expressed as $\text{Ric} - (1/2)g_{\mu\nu}R + R_{\mu\nu}\Lambda = (8\pi/c^4)G\tau_{\mu\nu}$, where $\text{Ric} = R_{\mu\nu} = R_{\mu\nu}^v$ the Ricci curvature TENSOR; a contracted Riemann tensor ($R_{\mu\nu}^v$), which vanishes in VACUUM, $\tau_{\mu\nu}$ the stress ENERGY tensor, $g_{\mu\nu} = (\partial/\partial y^\mu)(\partial/\partial y^\nu)((1/2)F^2)$ the metric tensor derived from a matrix diagonal in Finsler structure (the metric tensor is directly linked to the Ricci factor, however with only half the number of independent components: 10) and F the Finsler structure; with property: $F(x, \lambda y) = \lambda F(x, y)$, operating in Finsler geometry, not Riemann geometry, subsequently: Λ the cosmological constant (the energy density of space vacuum, assuming a stationary universe), R the SCALAR curvature, G the gravitational constant, and c the speed of LIGHT. Einstein had to admit to an error in his assumption of the UNIVERSE, being an EXPANDING UNIVERSE, as revealed by EDWIN HUBBLE (1889–1953) in 1915; leading to a significant adjustment for the cosmological constant (Λ). Additionally, under the condition of absolute zero the energy density tensor ($\tau_{\mu\nu}$) drops to zero as well. Defined by ALBERT EINSTEIN (1879–1955), as part of his GENERAL THEORY OF RELATIVITY, in 1915.

Vacuum pump

[general] Mechanism used to achieve high VACUUM or ultra-high vacuum. High vacuum can be reached by a variety of methods with pressures down to 10^{-12} Torr $\sim 10^{-10}$ Pa. Vacuum can be achieved by rotary piston (roots pump), bellows pumps or reciprocating piston pumps; single (limit: 5×10^{-3} Torr) or

double stage (limit: 1×10^{-4} Torr). In order to reach a deeper vacuum additional techniques need to be incorporated, often applied in stages or in unison. High vacuum techniques include fluid jet, cryogenic means (GAS is frozen and hence removed), chemical reactions with solid residue, and IONIZATION with an applied electric field that forces the ions/polarized molecules out, with lower limit down to 1×10^{-8} Torr. For even lower pressure stages special techniques are required, such as a turbomolecular pump, reaching 1×10^{-10} Torr. Combinations of pumping techniques and potentially the introduction of cryogenic cooling and the assistance of helium or hydrogen can result in pressures as low as 1×10^{-12} Torr, operating at temperatures in the order of 10 K. Generally, the process of vacuum application will involve removing the gasses trapped in the WALL of the container as well, a process called “outgassing.” Outgassing may require heating the container. Proper material selection for the construction of the PUMP and container are crucial for ultra-low pressure consistency, seals in the junctions as well as in the pumps are all influencing the final outcome. Most vacuum chamber are constructed of high-grade stainless steel.

Valence

[atomic, general] The number representing the combining or displacing power of an ATOM; number of electrons lost, gained, or shared by an atom in a compound. The valence is the number of hydrogen atoms with which an atom will combine, or the number it will displace. Valence electron describes any electron which is gained, lost, or shared in a chemical reaction. Usually valence electrons are the outermost electrons in the BOHR ATOM model.

Valence band

[atomic, energy, general, quantum] Overlapping of ENERGY bands of individual atoms, creating a continuous energy band instead of discrete energy levels as described by the Bohr model. Electrons that move beyond the valence band into the CONDUCTION BAND are free to move. The valence band can provide a mechanism for sharing of the outermost electrons in this shared energy band, specifically in a CONDUCTOR; whereas in a semiconductor or INSULATOR the valence electrons are held close by the respective atoms. For an insulator the conduction band and valence band are separated by an energy gap greater than 10 eV, whereas for a semiconductor the separation is 1 eV or less. For a semiconductor the conduction process can be facilitated by DOPING, for instance introducing GALLIUM in silicon introduces a shared energy band that provides an escape mechanism for electrons bound to silicon, leaving holes in the silicon (i.e., POSITIVE CHARGE surplus) (see Figure V.2).

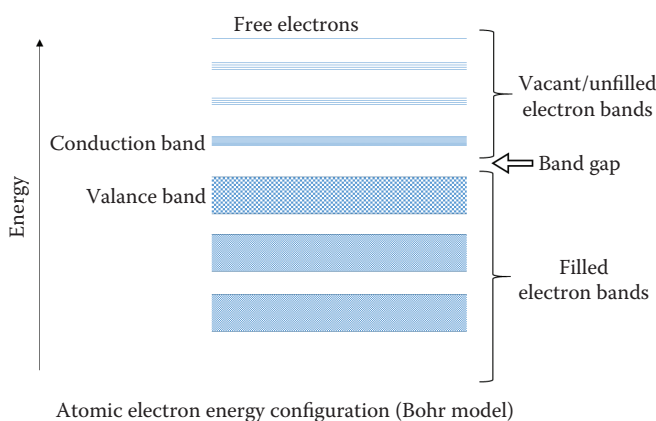


Figure V.2 Valence band concept illustrated by means of energy configuration for a hypothetical atom.

Valve

[fluid dynamics, thermodynamics] Closure mechanism applied to pipes and junctions in order to regulate the flow of fluids. Many types of valves exist, geared to achieve a specific goal or ease of use. Examples of

valves in use are butterfly, ball, gate, globe (one of many type found in water faucets as well as other applications), GATE VALVE or check valve. The flow control mechanism can depend on a seal or gasket made, for instance, out of rubber or cork, or can be METAL-on-metal with a through-hole that can be made to misalign. Check valves were common in the airflow regulation in older model automobiles with GAS MIXTURE supplied by a carburetor system, controlling the ANGLE of the flap that determines the opening area by depressing the gas pedal that connects through a level system (see Figure V.3).

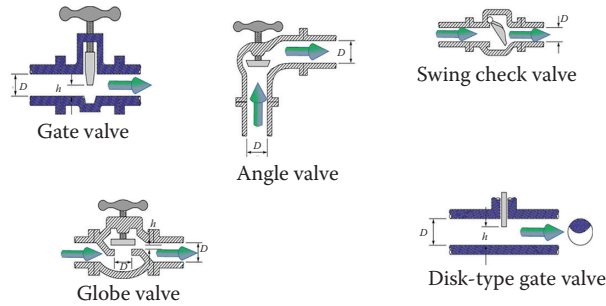


Figure V.3 Various valve designs.

Valves closure, Allievi's equations

[fluid dynamics] Equation of MOTION for flow and EQUATION OF CONTINUITY defined in 1925 by the Italian mechanical engineer LORENZO ALLIEVI (1856–1941) with specific relevance to the “WATER HAMMER” effect. The equation of motion is defined by the flow (Q ; [m^3/s]) and the change in height (h , also for instance associated with a diverging tube) as $Ag(dh/dx) + (\partial Q/\partial t) + kQ|Q| = 0$, where g is the GRAVITATIONAL ACCELERATION, A the cross-sectional area of the tube, and k is the equation of continuity reads $(\partial h/\partial t) + (v_{ch}^2/Ag)(\partial Q/\partial x) = 0$, where v_{ch} is the rate of change in flow (for instance, due to closure), or the velocity of propagation. Both are also found as $(\partial v/\partial t) + (1/\rho)(\partial P/\partial x)$, where the velocity v is the velocity parallel to the PIPE axis and averaged over the CROSS SECTION, P the pressure, and ρ the density of the FLUID. Alternatively, $E_Y(\partial P/\partial t) + (\partial v/\partial x)$, with E_Y the effective COMPLIANCE for the system.

Van Allen, James Alfred (1914–2006)

[astrophysics/astronomy, electromagnetism] Astrophysicist from the United States, specifically known for his discovery of the toroidal charged-particle bands encapsulating Earth: the VAN ALLEN BELTS (see Figure V.4).



Figure V.4 James Alfred Van Allen (1914–2006). (Courtesy of North American Space Agency [NASA], Washington, DC.)

Van Allen belts

[astrophysics/astronomy, electromagnetism] PLASMA belts around EARTH. The two torus shaped zones of energetic particles (primarily electrons and protons) emit RADIATION discovered and described by the astrophysicist from the United States, JAMES ALFRED VAN ALLEN (1914–2006). The belts represent particles that are “trapped” in the earth’s MAGNETIC FIELD configuration. The existence of the belts was confirmed by the spaceship Explorer I in 1958. The Van Allen radiation belts form part of the mechanism leading to the AURORA BOREALIS. The Van Allen radiation belts form a protection from the sun’s radiation and are formed resulting from the collision SHOCK WAVE of the sun’s SOLAR WIND with the earth’s magnetic field. Also known as the Van Allen radiation belts (see [Figure V.5](#)).

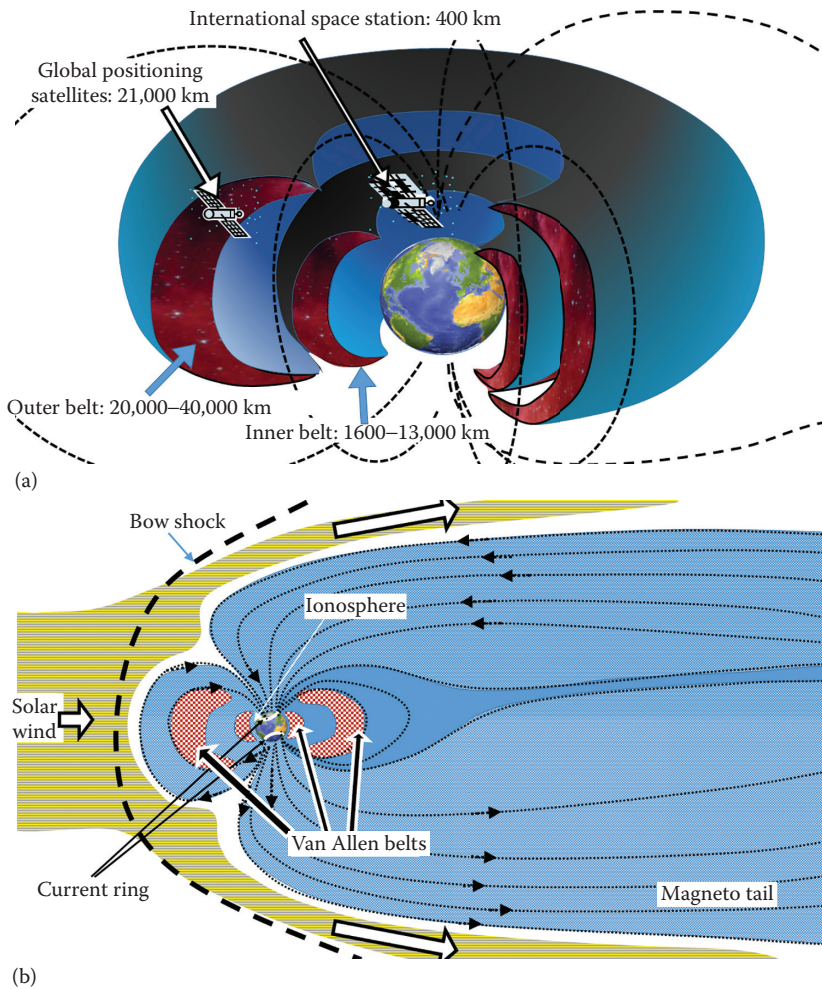


Figure V.5 (a,b) Van Allen belts.

Van de Graaff, Robert Jemison (1902–1967)

[general] Scientist, experimental PARTICLE physicist from the United States. Robert van de Graaff constructed the first belt-operated (electrostatic) charge GENERATOR in 1931 (see [Figure V.6](#)).



Figure V.6 Robert Jemison van de Graaff (1902–1967). (Courtesy of Massachusetts Institute of Technology, Cambridge, MA.)

Van de Graaff generator

[atomic, energy, nuclear] Static charge generator and collection station using a conveyor belt to transport charges that are generated by a high potential source, generating the equivalent to a CATHODE ray, positioned close to an insulating moving belt. The moving belt enters a hollow CONDUCTOR, while in contact with the sphere by means of a wire brush, transferring the charges on the belt to create a relatively high electric potential on a the hollow sphere over time, which is a function of the time and the radius of the sphere (generally several hundred thousand volts; see COULOMB'S LAW). The Van de Graaff generator was designed by ROBERT VAN DE GRAAFF (1902–1967) in 1931 to examine the conditions of high electrical potential and electric discharge. Static charge had been known for millennia prior to this invention, rubbing AMBER with

fur to generate a static charge, dating back to 600 BC recorded by the Greek astronomer Thales (Thales of Miletus: ca. 624–546 BC) (*also see* **WIMSHURST MACHINE**) (see [Figure V.7](#)).



Figure V.7 Van de Graaff generator design, with Robert van de Graaff (1902–1967) operating the charge conveyor belt. (Courtesy of Massachusetts Institute of Technology, Cambridge, MA.)

Van der Meer, Simon (1925–2011)

[general] Scientist from the Netherlands, who together with the Italian scientist Carlo Rubbia (1934–), led a team of scientists to the discovery of the “intermediate vector bosons” (in particular the W and Z bosons) in 1983, for which they received the Nobel Prize in Physics in 1984 (see [Figure V.8](#)).



Figure V.8 Simon van der Meer (1925–2011). (Courtesy of Conseil Européen pour la Recherche Nucléaire [European Council for Nuclear Research]. Copyright CERN, Geneva, Switzerland.)

Van der Pol, Balthasar (1889–1959)

[electromagnetism, theoretical] Electrical engineer from the Netherlands who recognized the characteristic NOISE in VACUUM tubes while operating under an alternating current of specific driving frequencies (see [Figure V.9](#)).



Figure V.9 Balthasar van der Pol (1889–1959). (Courtesy of International Telecommunication Union (ITU), Geneva, Switzerland.)

Van der Pol equation

[biomedical, electromagnetism, geophysics, mechanics] Second-order differential equation describing the damped OSCILLATION in a dynamic system that is not subject to CONSERVATION OF ENERGY. $(d^2x/dt^2) - \epsilon(1-x^2)(dx/dt) + x = 0$, where x can be a location or other time-dependent variable, t is time, ϵ is a coefficient indicating COMPLIANCE (including system nonlinearities) and dampening, specifically $-\epsilon(1-x^2)(dx/dt)$ is the definition of RESISTANCE or FRICTION. In case $-\epsilon(1-x^2)(dx/dt)$ is negative positive the term applies to “negative resistance” and applies, for instance, to the gain (nonlinear) of a power amplifier. This equation is also used in biological application to describe the ACTION POTENTIAL of neurons in a planar field geometry, other relevant uses are in SEISMOLOGY to model the MOTION of TECTONIC PLATES at a FAULT LINE and to describe RESONANCE phenomena in compliant media, such as in NONDESTRUCTIVE TESTING using ACOUSTICS. The equation will need to solved numerically with for instance specialized segmented methods as described by the RUNGE–KUTTA METHOD.

Van der Pol oscillator

[biomedical, electromagnetism, geophysics, mechanics, theoretical] An OSCILLATION (primarily electric, but additional applications in MECHANICS and geophysics are supported) which is nonlinearly damped and as such inherently nonconservational (*also see* OSCILLATION). A forced Van der Pol oscillator is described by $(d^2x/dt^2) + \epsilon(x^2-1)(dx/dt) + x - A\sin(\omega t) = 0$, where x is a Cartesian coordinate, t is time, ϵ is a coefficient indicating COMPLIANCE (including system nonlinearities) and dampening, $A\sin(\omega t)$ is the driving alternating source with AMPLITUDE A , and frequency $2\pi\omega$.

Van der Waals, Johannes Diderik (1837–1923)

[atomic, solid-state, thermodynamics] Physicist and engineer from the Netherlands whose main contribution to SOLID-STATE PHYSICS was the description of medium-range attractive forces, the VAN DER WAALS FORCE (also described as VAN DER WAALS BONDING). Van der Waals made significant theoretical contributions to the description and understanding of the EQUATION OF STATE of gases and liquids, some substantial contributions were in his doctoral thesis. In 1910 Johannes van der Waals was awarded the Nobel Prize in Physics (see [Figure V.10](#)).

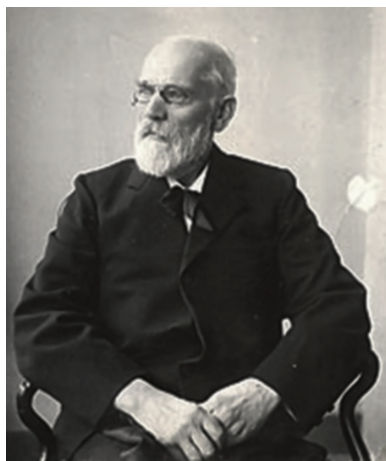


Figure V.10 Johannes Diderik van der Waals, (1837–1923). (Courtesy of Collection of the Van der Waals family.)

Van der Waals bonding

[biomedical, condensed matter, dynamics, general, nuclear, quantum, solid-state, thermodynamics] Also referred to as VAN DER WAALS FORCE. The force between molecules. This force distinguishes itself from the other known molecular forces defined as ELECTROSTATIC FORCE, covalent attraction, and hydrogen bonds. The Van der Waals force is a MACROSCOPIC force balance primarily applying to dipoles, both permanent and induced. Van der Waals forces act between molecules within the same structure, but also across an interface between different species of molecules such as at a surface, and work between atoms. The force is primarily derived from the fact that the atoms and molecules become charge polarized, the balance of negative and POSITIVE CHARGE shift to opposite sides respectively and forms an induced DIPOLE with limited lifetime or applies to permanent dipoles. The electrostatic interaction is also known as KEESOM FORCE. Groups of molecules can form charge distributions that lead to attractive force due to DISPERSION of the combined

charges forming multipoles. Examples of clear Van der Waals bonds are for instance found for graphite and clay (see [Figure V.11](#)).

Van der Waals force

[atomic] See VAN DER WAALS BONDING.

Van Helmont, Johannes (Jan) Baptista (1579–1644)

[general] Alchemist from the Netherlands attributed with the formal introduction of the concept of GAS as a material PHASE, not as a unique phenomenon (see Figure V.12).



Figure V.12 Johannes (Jan) Baptista van Helmont (1579–1644) c. 1674, painted by Mary Beale.

Van Laar equations

[thermodynamics] Description of mixtures with molar fractions of the (r -) constituents (μ^{mol}_i ; this forces $\sum_{i=1}^r \mu^{\text{mol}}_i = 1$). The van Laar equations are pertaining to binary mixtures specifically, yielding: $\ln \gamma'_1 = \ln \mu^{\text{mol}}_1 + (A/RT)/[1 + (A\mu^{\text{mol}}_1/B(1 - \mu^{\text{mol}}_1))]^2$ and $\ln \gamma'_2 = \ln(1 - \mu^{\text{mol}}_1) + (A/RT)/[1 + (B(1 - \mu^{\text{mol}}_1)/A\mu^{\text{mol}}_1)]^2$, where $A = \Delta H_{1,\text{mix}}$ and $B = \Delta H_{2,\text{mix}}$, with $H_{i,\text{mix}}$ the enthalpy of the constituent, and $\gamma'_1 = \gamma'_1(T, P, \mu^{\text{mol}}_1, \mu^{\text{mol}}_2, \dots, \mu^{\text{mol}}_{r-1})$ is the ACTIVITY of the ingredient (defining the excess in chemical potential relative to the state at reference pressure P_0 while at the same temperature) as a function of PRESSURE (P) and TEMPERATURE (T); however, not dependent on chemical composition.

Van Leeuwenhoek, Antonie Philips (1632–1723)

[biomedical, optics] Scientist, engineer, and merchant salesman from the Netherlands. Perfected the compound MICROSCOPE, reaching magnifications of 500X. Van Leeuwenhoek investigated biological materials such as bacteria, muscles, and spermatozoa. He also used his optical instrumentation to IMAGE

the **PERFUSION** of superficial vasculature and described capillaries. Considered the “father” of microbiology (see [Figure V.13](#)).



Figure V.13 Antonie Philips van Leeuwenhoek (1632–1723), painted by Jan Verkolje.

Van Musschenbroek, Petrus (1692–1761)

[energy, general] Physicist and mathematician from the Netherlands, instrumental in the development and experimental observations leading to the discovery of stored charge and the **CAPACITOR** (see [Figure V.14](#)).



Figure V.14 Petrus (Pieter) Van Musschenbroek (1692–1761), painted by Hieronymus van der Mij. (Courtesy of Leiden, Universiteits-Bibliotheek, Icones 147; Leiden, the Netherlands.)

Van Royen, Willibrord Snel (1591–1626)

[optics] See **SNEL** (“**SNELL**”), **WILLEBRORD SNEL VAN ROYEN** (**SNELLIUS**) (1591–1626).

Van't Hoff, Jacobus Henricus (1852–1911)

[biomedical, chemical, thermodynamics] Scientist and chemist from the Netherlands. Johannes van't Hoff received the Nobel Prize in Chemistry in 1901. One of Van't Hoff most memorable contributions is the definition of partial pressure of a dissolved solution as the OSMOTIC PRESSURE: $\Pi_{\text{osmotic}} = P - P_{jj} = (RT/v_{jj}) \sum_{k \neq j} \mathcal{Y}_k$, with $\mathcal{Y}_k = n_k/n = (x_k/M_k)/(\sum_{\ell=1}^r (x_\ell/M_\ell))$ the mole fraction of the dissolved constituent $_k$, with M_ξ the mean MOLECULAR WEIGHT OF SOLUTE $_\xi$, for the amount of constituent n_k summing to a total of solutes $n = \sum_{k=1}^r n_k$, x_ξ the fractional mass for constituent $_\xi$, P_{jj} the molar partial pressure of constituent $_j$ in SOLUTION, v_{jj} the volume of the INCOMPRESSIBLE FLUID per mole, PRESSURE P and TEMPERATURE T , and $R = 8.3145 \text{ J/molK}$ is the universal gas constant (see Figure V.15).

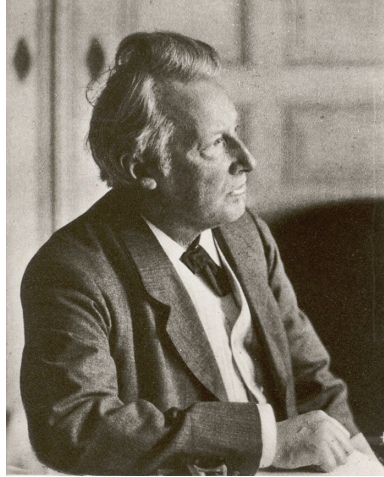


Figure V.15 Jacobus Henricus van't Hoff (1852–1911).

Van't Hoff equation

[biomedical, chemical, thermodynamics] Equation defining the pressure resulting from the gradient in concentration of solutes across a DISTANCE or a more physical BARRIER such as a SEMIPERMEABLE MEMBRANE. The Van't Hoff equation was defined by JACOBUS HENRICUS VAN'T HOFF (1852–1911), and is sometimes associated with the Starling equation. The OSMOTIC PRESSURE of a SOLUTION has the same value as if the particle solution would have as a GAS with the same volume and temperature as the solution. The OSMOTIC PRESSURE (Π_{osm}) can be expressed in the form used by the ideal gas law: $\Pi_{\text{osm}} = nRT/V = [C]RT$, where $R = 8.135 \text{ J/molK}$ is the gas constant, T the local temperature in Kelvin, n is the quantity of solutes in mol, and $[C]$ the concentration. The osmotic pressure is also referred to as the COLLOID OSMOTIC PRESSURE. Note that all solutions will add to the sum of the osmotic pressure of the LIQUID.

Van't Hoff factor

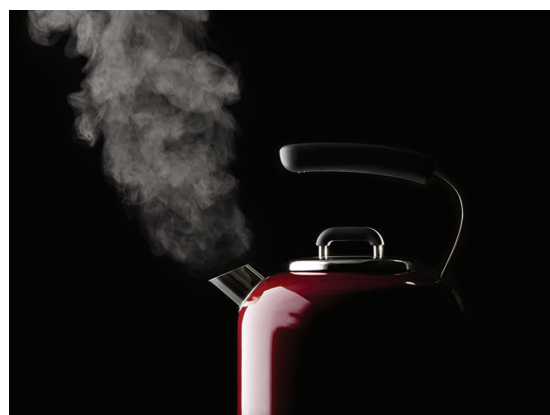
[fluid dynamics, geophysics, thermodynamics] Osmotic coefficient that applies to the partial pressure (Π_{osm}) of a SOLUTE described by the VAN'T HOFF EQUATION: $\Pi_{\text{osm}} = \Phi_{\text{osm}} RT \Delta[C]$, with $\Delta[C]$ the concentration gradient across a SEMIPERMEABLE MEMBRANE, where $R = 8.135 \text{ J/molK}$ is the GAS constant and T the local temperature in Kelvin. The expression $n_{\text{ion}} \times \Phi_{\text{osm}}$, where Φ_{osm} the osmotic coefficient or Van't Hoff factor, n_{ion} the number of ions respectively the solute concentration; yields the physically dissolved concentration contributing to the OSMOTIC PRESSURE. For NaCl (SALT) $\Phi_{\text{osm}} = 0.93$. Note that for electrolytes the Van't Hoff factor < 1 , however for nonelectrolytes the SOLUTION of particles becomes convoluted and complicated, rendering Van't Hoff factors < 1 , for instance, for hemoglobin the Van't Hoff factor $= 2.57$.

Van't Hoff law

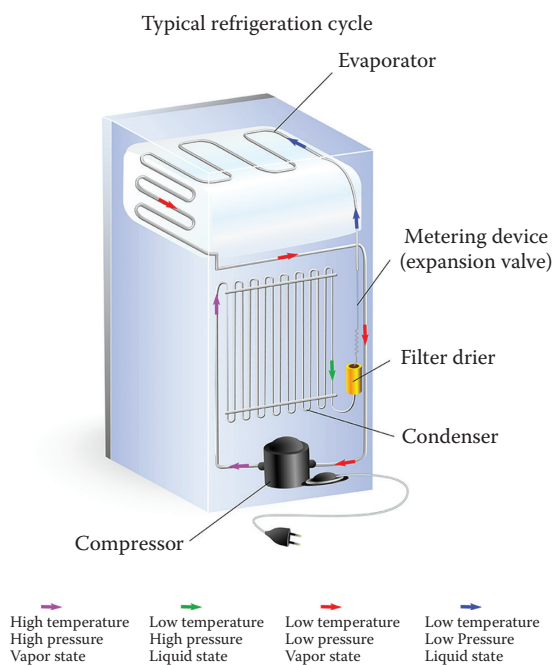
[biomedical, chemical, thermodynamics] See **VAN'T HOFF EQUATION**.

Vapor

[thermodynamics] Material phase of a medium where the molecules or atoms are spaced relatively far apart, generally achieved when exceeding the boiling point for the material, a gaseous phase. Note that a solid may transform into GAS under **SUBLIMATION** ("steam" rising from ice). The heat of vaporization (h_v , or **LATENT HEAT OF VAPORIZATION**, based on the constant temperature of the process) defines the **ENERGY** required to convert 1 kg of liquid phase into vapor at constant temperature. Water vapor is referred to as steam. The phases of a material are represented by the **PHASE DIAGRAM**. At the **TRIPLE POINT** (three phase): solid, liquid, and gas/vapor exist at the same time under the same conditions in equilibrium. When a vapor cannot be described as an **IDEAL GAS** the Van der Waals equation needs to be used, specifically when the vapor is a dense mixture. The reverse **PHASE TRANSITION** process is condensation from vapor to **LIQUID**, or from vapor to solid **desublimation**, respectively (see [Figure V.16](#)).



(a)



(b)

Figure V.16 (a) Vapor for boiling water and (b) vapor in the refrigeration cycle for freon or other cooling liquid.

Vapor pressure

[nuclear, thermodynamics] The pressure of a vapor in equilibrium with its condensed state (**LIQUID** or **SOLID**). The vapor pressure of a medium (P_v) is defined by the **Clausius–Clapeyron equation**: $\ln P_v = -(\Delta H_v/RT) + (\Delta S_v/R)$, where H_v is the enthalpy of vaporization, S_v the entropy of vaporization, T the local temperature, and $R = 8.3144621(75)$ J/Kmol the universal gas constant. The vapor pressure of mercury is of particular importance with respect to its use as an **ENERGY** transferral in certain types of nuclear power plants, primarily due to the toxicity of mercury. Other examples of **METAL** coolants are sodium, lead, and tin.

Vapor pressure equation

[atomic, fluid dynamics] See **CLAUSIUS–CLAPEYRON RELATION**.

Variable capacitor

[general] Plate capacitor with variable surface area, primarily used as a tuning mechanism for radios in the late 1900s. The change in surface area (A) directly influences the value of the CAPACITOR (C) as $C = \epsilon A/d$, where ϵ represents the permittivity of the medium between the plates and d the plate separation (generally, the tuning plate capacitor has multiple plates). The capacitance determines the RESONANCE FREQUENCY of the RC circuit (resistor (R)-capacitor (C) circuit, with specific time constant: $\tau_c = RC$); hence providing a mechanism of influencing the PHASE-LOCKED LOOP that will collect only the RADIO signal that matches the resonance frequency of the tuner (see Figure V.17).

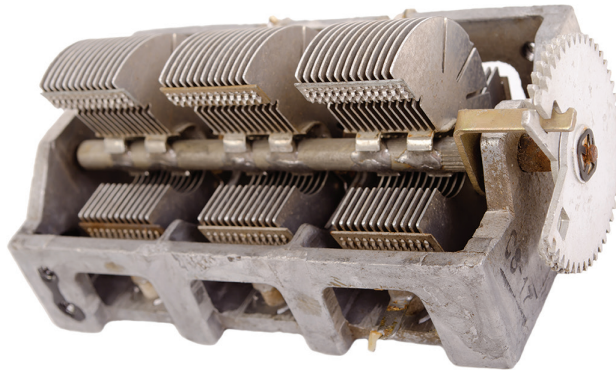
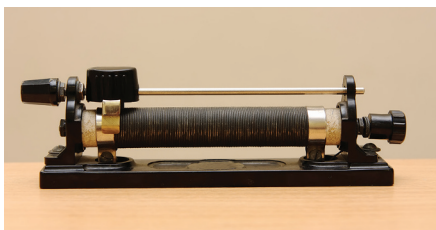


Figure V.17 Variable capacitor used for tuning an early model analog radio design.

Variable resistor

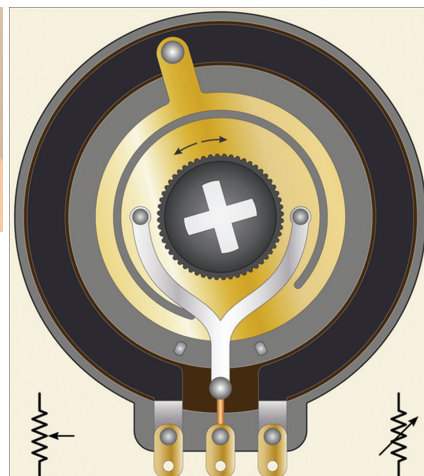
[general] Electrical device that can be adjusted for total resistance by means of rotation of a dial, which generally changes the length of a wire (ℓ) that the current passes through, hence changing the RESISTANCE since the SPECIFIC RESISTANCE ($\rho_{R, \text{spec}}$) of a METAL wire is a function of length: $R = \rho_{R, \text{spec}} \ell$. Also referred to as POTENTIOMETER (see Figure V.18).



(a)



(b)



Vector

Variable resistor

EPS 10

(c)

Figure V.18 (a) Variable resistor, (b) potentiometer, and (c) circuit diagram icons.

Variance (σ^2)

[computational, quantum, signal, thermodynamics] The square of the standard deviation for a series (with sample size: N) of measurements (x_i), defined as $\sigma^2 = 1/(N-1) \sum_{i=1}^N (x_i - \bar{x})^2$, with the mean: $\bar{x} = 1/N \sum_{i=1}^N x_i$. The variance provides an indication of the physical spread in data, how far are the data removed from the mean value, and hence is an indication of risk. A large variance is an indication of a broad spread of the measured values, not particularly correlated to the likelihood (probability distribution), more an indication of how far out can numbers enter into the analysis with respect to the mean value.

A variance close to zero is an indication of a very close grouping of data. Additionally, variance is one of the moments of a distribution. The standard deviation for a sample distribution is the square root of the variance. In THERMODYNAMICS the concept of “variance” (F_{var}) relates the PHASE change of a chemical reaction to the number of coexisting phases of a system with r constituents defined as $F_{\text{var}} = r + 2 - q - \tau_{\text{ch}}$, where q is derived from the Gibbs PHASE RULE as the system operating in a q -phase state (heterogeneous stable equilibrium of coexisting phases; allowing each phase to be modeled as a simple system), and τ_{ch} represents the ordered number of potential chemical reactions, τ_{ch} is captured as a series (two constituents can have maximally one reaction, yielding $\tau_{\text{ch}} = 0,1$) (see Figure V.19).

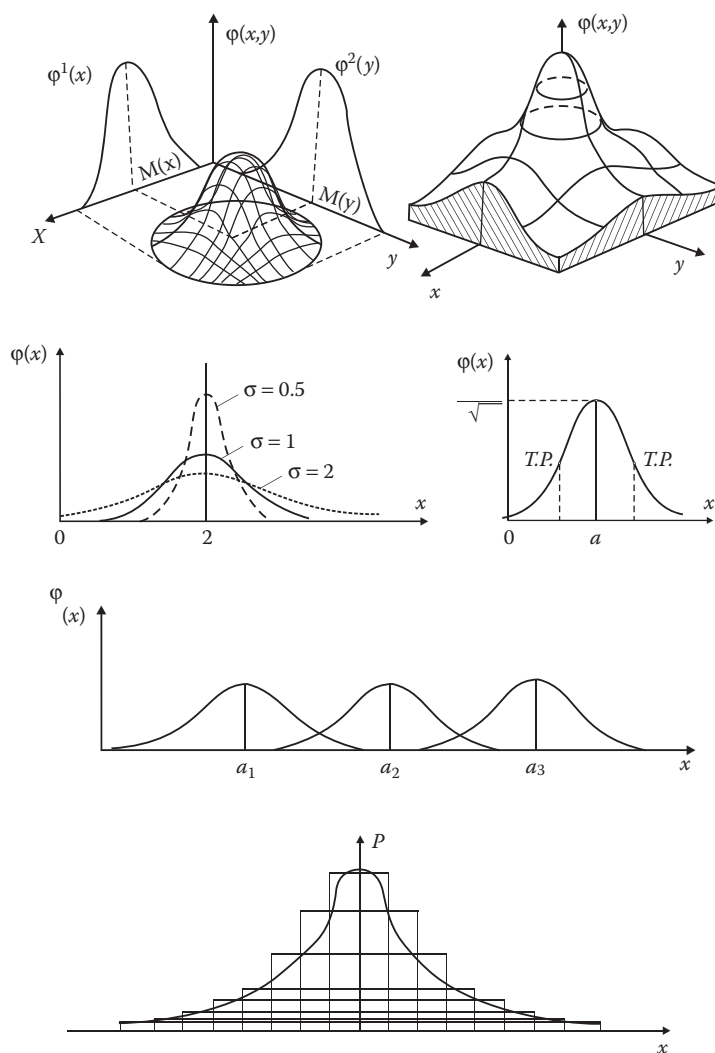


Figure V.19 Statistical variance.

Vector boson

[general] Bosons that are the exchange particles in a weak nuclear interaction, in particular the W and Z bosons. The WEAK INTERACTION delineates the interaction between electrons and neutrinos.

Vein

[biomedical] Anatomical feature, BLOOD vessel that is returning blood to the HEART. Blood in the veins is generally oxygen poor, except for the veins carrying blood from the lungs, which is oxygen rich. Veins have valves in intermittent locations to prevent blood from pooling and flowing back due to the lack of applied pressure. Veins are fairly similar to arteries, with the exception that the veins do not have a muscular WALL and rely on externally applied pressure from SKELETAL MUSCLE to provide the pumping action, mediated by the valves to force the flow in the direction of the heart (see Figure V.20).

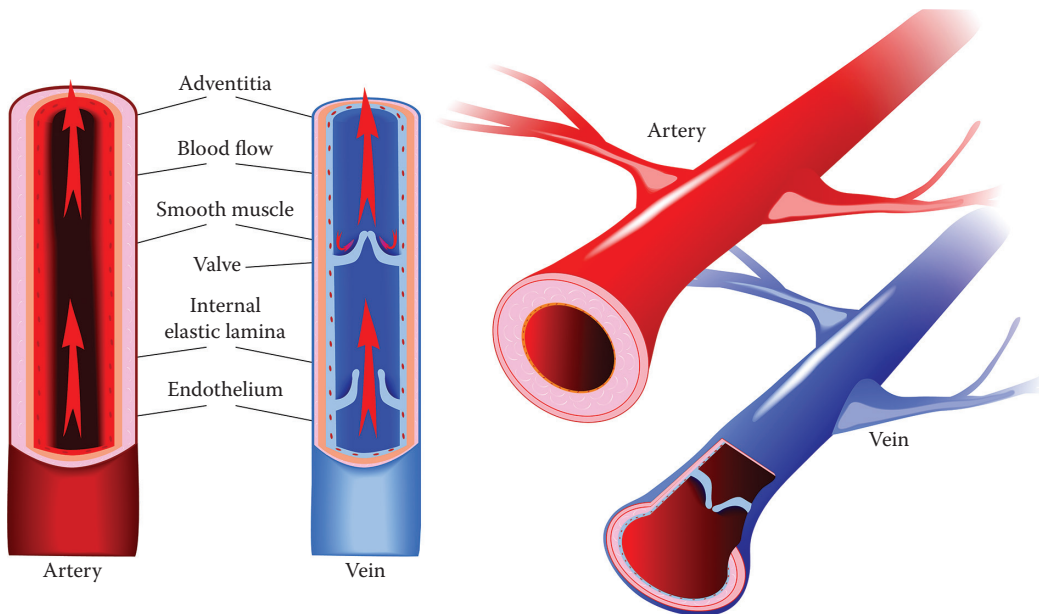


Figure V.20 Vein, blood vessel.

Velocity ($\vec{v}$)

[acoustics, biomedical, biophysics, dynamics, electromagnetism, engineering, general, geophysics, optics, ultra-fast phenomena] (syn.: speed) {use: energy, motion} Vector describing the MAGNITUDE and direction of the change in location (i.e., displacement) as a function of time: $\vec{v} = dL(x(t), y(t), z(t))/dt$, where $L(x(t), y(t), z(t))$ is the position in the three-dimensional Cartesian coordinate system as a function of time t .

Velocity potential

[fluid dynamics, geophysics] A dynamic function that has many similarities with potential theories of attraction (e.g., potential ENERGY), ELECTRICITY and magnetism, and ELECTROSTATICS (e.g., electrical potential). The velocity potential defined by the energy involved in FLUID flow moving from a fixed point A^* to variable point P^* is for an irrotational MOTION defined as $\phi = -\int_{A^*}^{P^*} (u dx + v dy + w dz)$, where in CARTESIAN COORDINATES $u = -(\partial\phi/\partial x)$ is the velocity in the x -direction, $v = -(\partial\phi/\partial y)$ is the velocity in the y -direction, and $w = -(\partial\phi/\partial z)$ is the velocity in the z -direction. For a VORTEX motion the velocity potential needs to include directional information defined by $\psi = \int_{A^*}^{P^*} (\chi_x \cos \Theta_x u + \chi_y \cos \Theta_y v + \chi_z \cos \Theta_z w) ds$, where $\cos \Theta_i$

described the respective **ANGLE** for all velocities with respect to the normal to the curved velocity profile and χ_i is a proportionality constant. The velocity gradients are now defined by $dw/dz = ((\partial\phi/\partial x) + (\partial\phi/\partial y)) + i((\partial\psi/\partial x) + (\partial\psi/\partial y))$, respectively, and so on. In turn the velocity profile for rotational flow is now defined by $\phi = (\kappa/4\pi) \iiint (\chi_x \cos \vartheta_x (\partial/\partial x') + \chi_y \cos \vartheta_y (\partial/\partial y') + \chi_z \cos \vartheta_z (\partial/\partial z')) (1/r) ds'$, where $\kappa = \varpi' \sigma'$ is a measure of the strength of the vortex with ϖ' an indication of the vorticity and σ' a **SURFACE ELEMENT ON THE VORTEX** filament, s' denotes the surface bounded by the vortex element, and $r = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2}$ with (x', y', z') the location on the surface bounded by the vortex filament of importance and (x, y, z) the location in P^* where the velocities (u, v, w) will need to be derived. The work (W) done by rotational motion of an incompressible **LIQUID** can be related to the velocity profile (in accordance with general potential theories) as $W = (1/2)\rho \iiint [(\partial\phi/\partial x)^2 + (\partial\phi/\partial y)^2 + (\partial\phi/\partial z)^2] dx dy dz$ (see **Figure V.21**).

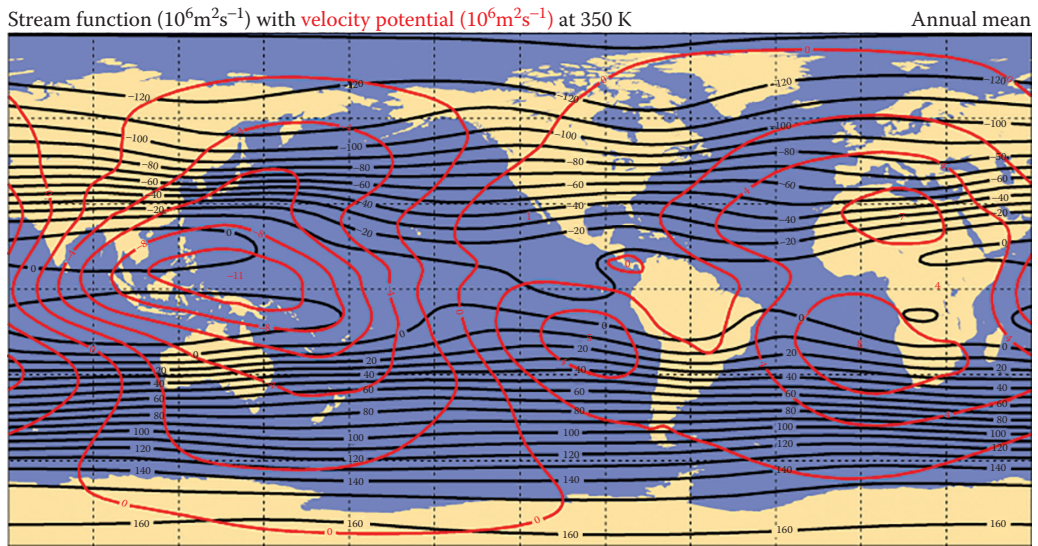


Figure V.21 Velocity potential for the geographic wind flow, averaged over 1 year. (Courtesy of University of Reading, Reading, UK; European Centre for Medium-Range Weather Forecasts [ECMWF].)

Ventilation

[biomedical, fluid dynamics, mechanics] Expansion and contraction of the chest cage coinciding with respective inspiration and expiration, known as breathing (*also see* **RESPIRATION**).

Ventilator

[biomedical, chemical, electronics, fluid dynamics, mechanics] Mechanical device providing an assist function to transport oxygen into the lungs by forcing **AIR** into the lungs by a **PUMP** mechanism. Ventilators are required during anesthesia since the normal muscular action that facilitate the volume **EXPANSION** of the lungs (inhaling) by means of either pulling down the diaphragm in the stomach by contraction (the diaphragm in relaxed state is curved upward), or elevating the ribs in the rib cage is rendered inoperable. Exhaling is an elastic process and relies on the **ANATOMY** to return to the position with the lowest **ENERGY**. In addition to mechanical ventilators that operate at the same frequency as with respect to unchallenged **ACTIVITY** for the person in question, other mechanisms are required as well. The **VENTILATION** process for premature babies is challenging to the extremely small size of the infants, size of a fist. In some cases the

use of high-frequency modulation is used to induce a net flow, operating under kHz acoustic perturbation. The high-frequency approach provides a minimal net force/pressure to the lungs of the infant, thus preventing damage to the lungs resulting from excessive force (see [Figure V.22](#)).



Figure V.22 Neonatal baby connected to special design ventilator specifically designed for the small tidal volume and respiratory rate boundary conditions.

Venturi, Giovanni Battista (1746–1822)

[fluid dynamics] Engineer and scientist from Italy who described the “suction” aspect of flow when passing through a narrowing tube with a hole in the wall of the tube in 1791 (see [Figure V.24](#)).



Figure V.24 Giovanni Battista Venturi (1746–1822).

Venturi

[fluid dynamics] Mechanical configuration with respect to flow that results in an increase in flow velocity with a resulting drop in pressure, based on Bernoulli's law. Two boats that are traveling side by side will cause a localized increase in flow velocity due to the narrowing passage between the boats (specifically due to the curved outer hull of the ships), which will force the boats to move closer together due to the undisturbed pressure experienced on the hull of the boats on the perimeter. Another example is the flow of water over a container with chemical SOLUTION, drawing the chemical solution into the flow stream as a result of a venturi with an appropriately placed opening connecting to the reservoir. This mechanism is used to

facilitate the diluted and controlled spread of fertilizer or weed killer. The physical process of creating “suction” by means of flow is referred to as the venturi effect. The process is named after the Italian scientist GIOVANNI BATTISTA VENTURI (1746–1822) who described this phenomenon in 1791. The venturi effect is also responsible for creating the mechanical MOTION of loose tissues in the nose and throat (airways in general) resulting in the snoring SOUND (see [Figure V.23](#)).



Figure V.23 Asthma inhaler with venturi for drug distribution: nebulizer.

Venus

[astrophysics/astronomy, general] Second PLANET from the SUN with an average diameter of 12,103.6 km, a mass of 4.86732×10^{24} kg, and an average surface temperature of 480°C. One SPIN revolution takes 243 Earth days, in the opposite direction with respect to earth’s rotation, and the revolution around the Sun lasts 225 Earth days. The Magellan space mission has explored Venus with great detail, and a total of 40 spacecraft have been sent to Venus so far (see [Figure V.25](#)).

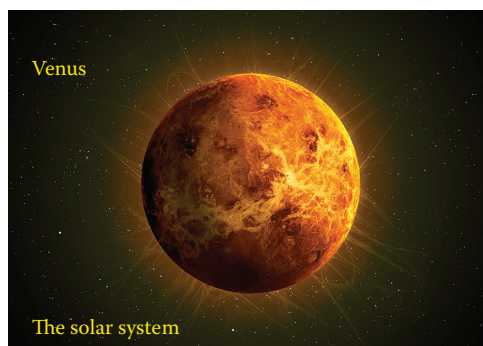


Figure V.25 Venus.

Verlet method

[computational] Numerical integration technique, specifically designed to solve Newton's EQUATIONS OF MOTION, based on a TAYLOR EXPANSION with respect to the coordinates, introduced by the French physicist Loup Verlet (1931–) in 1967.

Versorium

[general] Elementary ELECTROSCOPE. One of the first devices used to measure static charge. The versorium was invented by the English astronomer and physician SIR WILLIAM GILBERT (1544–1633) around 1600 (see [Figure V.26](#)).

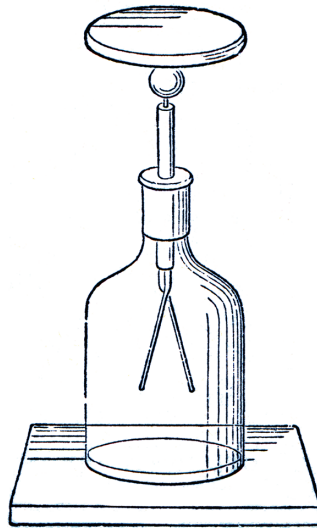


Figure V.26 Electroscope that uses the same principle as the versorium, a rod that can pivot freely. The original versorium had a close similarity to a compass needle, only for charge (i.e., electric field) and not for magnetic field. The illustrated gold-leaf electroscope was developed almost two centuries later, in 1787, by the clergyman and physicist Abraham Bennet (1749–1799) from Great Britain, following the introduction of the A pith-ball electroscope, which was a ball suspended from a thread, invented in 1754 by school teacher and physicist John Canton (1718–1772) from Great Britain, inspired by Benjamin Franklin (1706–1790) from the United States.

Vesalius, Andreas (1515–1564)

[biophysics, general] Scientist from Belgium describing the first documented dissection of the human ANATOMY: *Humani Corporis Fabrica* in 1543. This was a dissention from the Galenian school of biological

investigation (see **CLAUDIUS GALENUS** [130–201] also named “Galen”), focusing on animal observation and bodily composition examination (see **Figure V.27**).

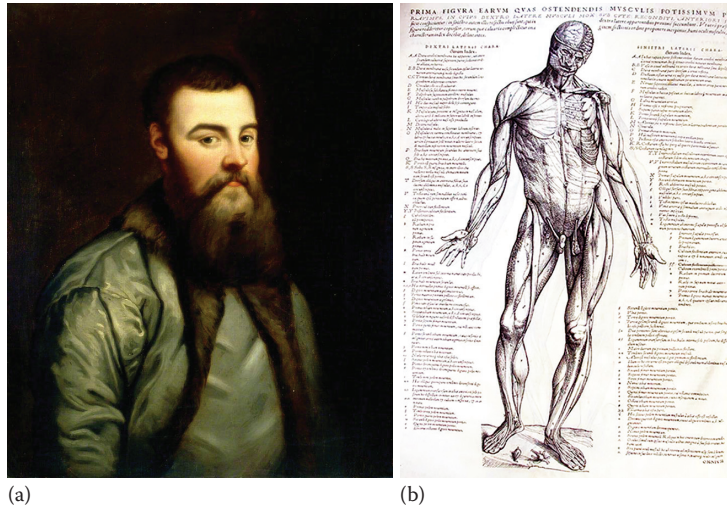


Figure V.27 (a) Andreas Vesalius (1515–1564). (Courtesy of UCL Media Services; Collection: University College London Hospitals, London, Great Britain, example of the anatomic artwork by Andreas Vesalius.) (b) Epitome of Vesalius, Basel, 1543. (Courtesy of University of Glasgow Library, Special Collections; Glasgow, UK.)

Vibration

[acoustics, mechanics, solid-state, thermodynamics] Rhythmic motion with respect to a point of equilibrium, often with fixed frequency. Vibrations can be rotational (including “scissor action”), linear/translational, and “spherical” (general three-dimensional) EXPANSION, and are generally not confined to any single dimensional orientation; for instance, a drum SKIN, or GUITAR casing (acoustic guitar) can have a variety of oscillatory modes. The acoustic vibration, pressure wave, generates sound. Vibrations require an ENERGY source to support the MOTION, when the source is removed the OSCILLATION will dampen based on the elastic modulus of the medium. Vibrations supported by an external FORCE (F) obey the WAVE EQUATION with respect to the displacement $u(\vec{r}, t)$ as function of location $\vec{r}$ and time t : $\nabla^2 u(\vec{r}, t) = (1/v_s^2)(\partial^2 / \partial t^2)u(\vec{r}, t) - F$, where the displacement wave propagates through the medium with velocity v_s , the speed of SOUND for an acoustic wave (∇^2 is the Laplace operator, defining a second-order derivative with respect to location). Whistling generates a vibration with virtual single frequency, described by a sinusoidal function for the AMPLITUDE: $A(t) = A_0 \sin(\omega t - \phi)$, where $\omega = 2\pi\nu$ the ANGULAR VELOCITY and ν the frequency (the term “frequency” was introduced by GALILEO GALILEI [1564–1642]); as well as ϕ a PHASE difference depending on the boundary conditions. Vibrations are periodic motions with a periodicity or time constant that repeats the process for each cycle: $T = 1/\nu$, the total duration of a single oscillation (period). Vibration of an ELECTRIC CHARGE will provide a localized alternating current with associated alternating electric field and ensuing induced alternating MAGNETIC FIELD, providing an electromagnetic wave (PHOTON). Vibrations will have a base frequency and often higher harmonics superimposed. The harmonics will provide “COLOR” to a sound, or spectrum in the acoustic or optical analysis. Molecular vibrations are the main source for temperature, the mean kinetic energy; next to electronic vibrations as a result of temperature from a source of signal noise superimposed on the data, requiring filtering and smoothing to regain the clarity of the SIGNAL information. Undamped (“undamped”) or underdamped oscillations with a continuous force source will result in

RESONANCE phenomena that can lead to excessively large amplitudes. It is also referred to as oscillation (see [Figure V.28](#)).



Figure V.28 Vibration: (a) soil compactor based on tempering by combustion engine and (b) weight-loss vibration belt.

Villard, Paul Ulrich (1860–1934)

[general] Chemist from France who discovered gamma RADIATION in 1903. The studies of Villard on radium involved a PHOTOGRAPHIC PLATE that was sealed by a sheath of lead (known to stop the already discovered alpha-particles), but still yielded exposure, which was shown to consist of two types of radiation, one being beta rays (electron radiation, also known at the time) and a new unknown type of radiation. ERNEST RUTHERFORD (1871–1937) proposed the name gamma rays since they were more penetrating than alpha- or beta rays (named by Rutherford in 1899). Villard made the introduction of quantifying radiation exposure, later quantified by the unit Röntgen, after the elementary work performed by WILHELM CONRAD RÖNTGEN (1845–1923). These exposure QUANTIFICATION efforts still determines the current field of dosimetry in both medical applications and nuclear power plants (see [Figure V.29](#)).



Figure V.29 Paul Ulrich Villard (1860–1934).

Viscoelastic

[biomedical, fluid dynamics, mechanics, solid-state] Non-Newtonian behavior that has both viscous and elastic characteristics under deformation. Viscoelastic media have time-dependent strain, whereas a viscous medium has a linear relationship for strain under flow and deformation conditions; that is, exposure to stress. A viscoelastic medium has a dependence to shear rate with respect to the equation of motion. Examples of viscoelastic behavior are pseudoplastic and dilatant media. The equation of motion for fluids is generally defined by the Navier–Stokes equation for the velocity of motion $\vec{v}$ in a liquid with density ρ under applied forces $\vec{F}$ and pressure P as a function of time (t), which will integrate compensation for elastic dampening: $\rho((\partial\vec{v}/\partial t) + (\vec{v} \cdot \nabla)\vec{v}) = \rho\vec{F} - \nabla \cdot P + \eta_{\text{visc}} \nabla^2 \vec{v} + (\eta_{\text{bulk}} + (\eta_{\text{visc}}/3)) \nabla(\nabla \cdot \vec{v})$, where $\eta_{\text{visc}} = (5/16\sqrt{\pi})(\sqrt{(k_b T)/\sigma_r^2 \Omega_c^{2,2}})$ defines the viscosity ($k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann constant, temperature T , σ_r molecular diameter, $\Omega_c^{2,2} = n_i n_j \int_{-\infty}^{\infty} \int_{4\pi} \{\phi_i(v^{*i})\phi_j(v^{*j}) - \phi_i(v^*)\phi_j(v^{**})\} \chi \sigma_R d\Omega d^3 v$ the Fokker–Planck collision integral, a special case of the Boltzmann collision integral ($\sigma_R = 1/4(Z_i Z_j / 4\pi \epsilon_0 m)^2 (1/\chi^2 \sin^4(\varpi/2))$ the RUTHERFORD CROSS SECTION; $m = m_i m_j / (m_i + m_j)$ the average mass for a two-component medium, Z_n the respective charges, $\epsilon_0 = 8.85419 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ the permittivity of free space, χ the SCALAR location within the vector potential, ϖ the ANGLE of impact, and $\phi_n(v^{**})$ the respective intermolecular potential for the interdependent constituents), η_{bulk} the bulk viscosity and the KINEMATIC VISCOSITY associated with the flow: $\eta_{\text{kin}} = \eta_{\text{visc}}/\rho$. The viscosity η_{kin} is linked to the material STRESS ($\sigma_s(t)$) and STRAIN ($\epsilon_s(t)$) as $\sigma_s(t) = \eta_{\text{kin}}(d\epsilon_s(t)/dt)$. The elastic compensations are introduced by the Volterra equations linking stress and strain as $\epsilon_s(t) = (\sigma_s/E_{Y,\text{creep}}) + \int_0^t K(t-t')[\partial\sigma_s(t')/\partial t']dt'$, where $K(t)$ is a CREEP function; $\sigma_s(t) = E_{Y,\text{relax}}\epsilon_s(t) + \int_0^t R(t-t')[\partial\epsilon_s(t')/\partial t']dt'$, $R(t)$ a relaxation function, E_Y a elastic modulus for creep and relaxation (*also see DAMPER*). For a Maxwell damper the stress–strain relationship can be written as $d\epsilon_{\text{tot}}(t)/dt = \sigma_s(t)/\eta_{\text{kin}} + (1/E_Y)[d\sigma_s(t)/dt]$. Alternatively, for the Kelvin–Voigt model the stress–strain relationship can be written as $\sigma_s(t) = E_Y\epsilon_s(t) + \eta_{\text{kin}}[d\epsilon_s(t)/dt]$. More complex models are available, combining serial and parallel elastic arrangement of the first two models, for instance, the Maxwell–Wiechert (also known as the generalized Maxwell model, after JAMES MAXWELL [1831–1879], respectively with contributions by Emil Wiechert [1861–1928]) approach. An extreme example of viscoelastic behavior is for chewing gum. BLOOD behaves as a Newtonian liquid only for high shear rate (greater than 100 s^{-1}) and for large vessel diameters (see [Figure V.30](#)).

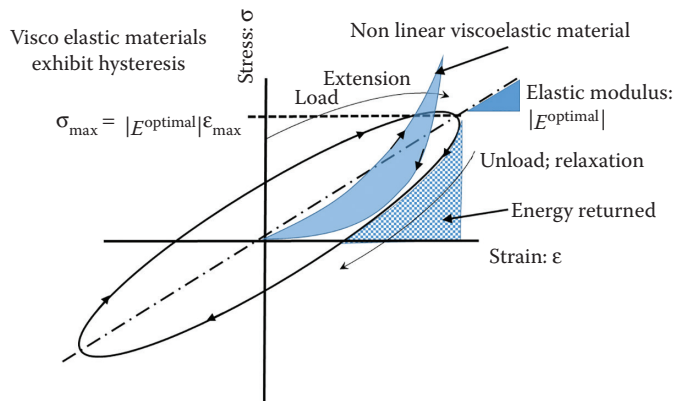


Figure V.30 Diagram representing the viscoelastic behavior for a medium.

Viscoplastic

[fluid dynamics, general, mechanics] Decomposition of the strain rate into an elastic and a plastic component; application of elastic stress–strain applied to the strain rate; the use of plastic flow potential and compliant with the plastic flow rule. The plastic flow rule defines the conditions of flow under multiaxial loads, with additional boundary condition confinement provided by the evolution of the state variables with respect to PLASTIC STRAIN and RESISTANCE of the state variables to flow (analogous to yield stress). The strain rate decomposition is formulated by separation of the rate of STRAIN ($\epsilon_s(t)$) over time in elastic (e) and plastic (p) components: $(d/dt)\epsilon_s^{ij}(t) = (d/dt)\epsilon_{s,e}^{ij}(t) + (d/dt)\epsilon_{s,p}^{ij}(t)$, note $\epsilon_s^{ij}(t) = 1/2((\partial v_i/\partial x_j) + (\partial v_j/\partial x_i))$, with v_n the velocity of flow in the respective directions. This provides for the elastic strain rate: $(d/dt)\epsilon_{s,e}^{ij}(t) = E_{Yijkl}^*(d/dt)\sigma_s^{kl}(t) = [(1 + \nu_{\text{Poisson}})/E_Y](d/dt)\sigma_s^{ij}(t) - (\nu_{\text{Poisson}}/E_Y)(d/dt)\sigma_s^{kk}(t)\delta_{ij} + \alpha(dT/dt)\delta_{ij}$, where E_{Yijkl}^* is referred to as the Elastic COMPLIANCE tensor (Note: inverse to the generalized elastic modulus), E_Y is the Young's modulus, $\nu_{\text{Poisson}} = -(\epsilon_{\infty}/\epsilon_z) = -(\epsilon_{\text{transverse}}/\epsilon_{\text{logitudinal}})$ the Poisson ratio where ϵ_i is the strain in direction i , δ_{ij} the Kronecker delta, α_m a material property, and T the temperature (also see CREEP) (see Figure V.31).

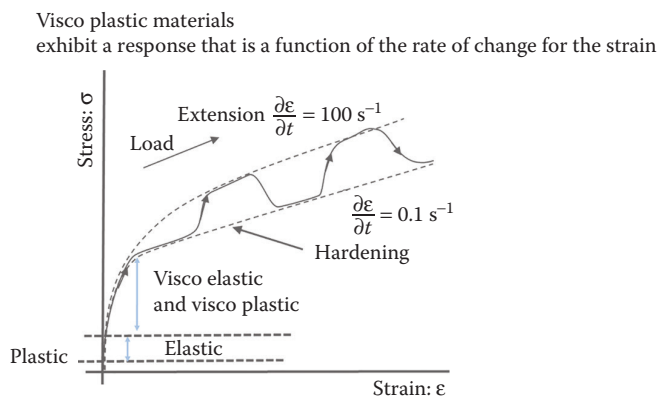


Figure V.31 Diagram representing the viscoplastic behavior for a medium.

Viscosity

[fluid dynamics, general, mechanics] The relation in torque between a rotating object and a stationary object separated by a LIQUID.

Viscosity (η)

[atomic, biomedical, computational, fluid dynamics, mechanics, nuclear, solid-state] Apparent RESISTANCE a fluid applies to a body in MOTION, and even itself (equating to flow resistance), measured as a standard by dropping a sphere in a FLUID and measuring the rate of decent, expressed as $\eta = [2(\rho_{\text{sphere}} - \rho_{\text{liquid}})gR^2]/9v$, where ρ the density of the sphere or LIQUID respectively, g the GRAVITATIONAL ACCELERATION, R radius of the sphere, and v velocity of the sphere dropping through the liquid (see also DYNAMIC VISCOSITY OR COEFFICIENT OF VISCOSITY). Proportionality constant connecting the SHEAR STRESS (τ_s) between two plates in linear parallel movement with respect to each other and the speed of respective motion $\tau_s = F/A = \eta(U/h)$, where A is the

area of the contact surface between the two planes, b the separation DISTANCE between the planes, F the force applied to move one of the plates, and U the constant velocity of the MOTION. Another way of describing the viscosity of flow is in a tube where a column of flow experiences the resistance from the neighboring shell layer as a FRICTION force (F_f) expressed as a function of radius (r): $F_f(r) = \eta 2\pi r L (dv/dr)$, where L the characteristic length over which the pressure drop is measured, dv/dr the radial velocity gradient, for a laminar Newtonian flow the flow velocity will be a quadratic function with respect to radius, forming a parabolic velocity pattern with the maximum flow velocity in the center of the tube. Units centiPoise, dimensions: ML^2T^{-1} (also see NEWTONIAN FLUID, SHEAR THICKENING, and SHEAR THINNING) (see Figure V.32).

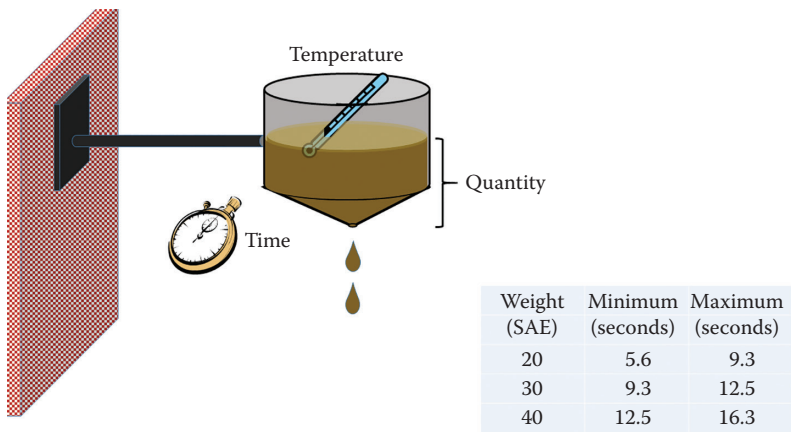


Figure V.32 Impact of the particulate concentration on the viscosity.

Viscosity, apparent

[general] See APPARENT VISCOSITY.

Viscosity, dynamic (η_{dyn})

[atomic, biomedical, computational, fluid dynamics, mechanics, nuclear, solid-state] Viscosity pertaining to the “mechanical flow resistance” of a FLUID with the neighboring shell layer as a FRICTION force (F_f) is expressed as a function of DISTANCE to the WALL of the solid (y): $F_f(r) = \eta_{dyn} A (dv/dy)$, where A is the area of interaction with, for instance, a flat wall, where $A = Lw$, L the characteristic length of interaction over a width w , also: dv/dr . the shear velocity gradient. Units centiPoise and dimensions: $ML^2 T^{-1}$. The wall can also be the surface of a sphere subject to flow, dropping through a LIQUID. The area of the sphere (only the area subject to flow) will replace the linear area mentioned earlier for the wall. The DYNAMIC VISCOSITY of gases can be determined by the absolute MANOMETER of Knudsen.

Viscosity, intrinsic

[fluid dynamics, general, nuclear] $[\eta] = \lim_{[c] \rightarrow 0} (\eta_{reduced})$, where $[c]$ is the SOLVENT concentration and $\eta_{reduced}$ the REDUCED VISCOSITY.

Viscosity, kinematic

[fluid dynamics] The standard viscosity multiplied by the GRAVITATIONAL ACCELERATION (g) and divided by the DENSITY (ρ) of the FLUID: $\eta_K = \eta(g/\rho)$, units St , dimensions: L^2T^{-1} . One specific example of KINEMATIC VISCOSITY applies to MOTOR OIL. To insure uniformity, the Society of Automotive Engineers (SAE) has designed specific tests to measure the flow rate of oil. The OIL grades are designated by a “weight” or viscosity grade, for instance, referred to as an SAE number. The SAE number is defined by a process that measures the time it takes for a predetermined quantity of oil to seep through an opening in a canister with a fixed diameter performed at a standard temperature. The temperature used for grading the viscosity of motor oil is generally $100^\circ C$. This temperature has been chosen to resemble the operating temperature for the average automobile engines. The higher the “weight” number in the SAE rating system, the thicker the oil, with respective slower flow; this refers to a single weight oil. In order to compensate for the changing temperature and LOAD conditions multiviscosity lubricants have been introduced. Multiweight lubricants are created by adding what is known as viscosity improver (VI) additives to oil, which makes the oils remain thicker at higher temperatures. Multiweight oils is designed to remain relatively constant in viscosity over a broad range of temperatures. The SAE classification for multigrade oils is described by two viscosity grades; for example, 10W-30, a common multigrade oil used in modern engines. Older engines were prescribed thicker oils such as 20W-50. The first number designates the viscosity at low temperature (“10W”), while the second number (“30”) represents the viscosity at $100^\circ C$. The “W” refers to cold weather use, and is derived from Winter. The viscosity rating scale for lubricants has been standardized by the American Petroleum Institute (API). The oil specifications from the ENGINE manufacturer will best suit all of the LUBRICATION requirements, over the lifetime of the engine. The actual MEASUREMENT temperature used to evaluate the performance (e.g., “cold start”) and define the grade of oil depends on the W-grade. For example, an oil with grade SAE 5W must be evaluated at $-35^\circ C$, while an SAE 10W grade oil must meet the shear rate viscosities ranges defined by the SAE J300 standards at $-30^\circ C$ (see Figure V.33).

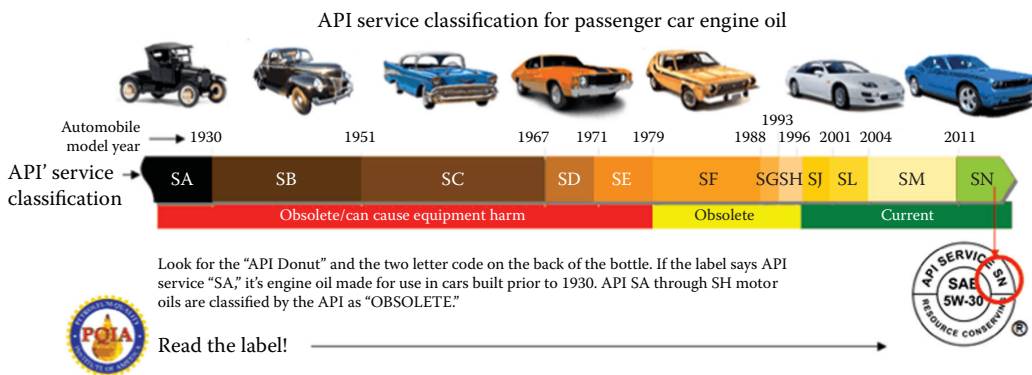


Figure V.33 Kinematic viscosity.

Viscosity, reduced

[fluid dynamics, general, nuclear] $\eta_{\text{reduced}} = \eta_{\text{specific}}/[c]$, where $[c]$ is the colloid concentration and η_{specific} the SPECIFIC VISCOSITY.

Viscosity, relative

[fluid dynamics, general, nuclear] $\eta_r = \eta_{\text{suspension}} / \eta_0$, where $\eta_{\text{suspension}}$ is the colloid viscosity and η_0 the viscosity of the SOLVENT.

Viscosity, specific

[fluid dynamics, general, nuclear] $\eta_{\text{specific}} = (\eta_{\text{suspension}} - \eta_0) / \eta_0$, where $\eta_{\text{suspension}}$ is the colloid viscosity and η_0 the viscosity of the SOLVENT.

Viscosity, static

[fluid dynamics, mechanics] Friction between two plates, one plate is moving with respect to the other plate, creating a force with respect to the stationary plate. Units $\text{centiPoise} \times \text{gram} \times \text{m}^{-3} = \nu$, dimensions: $M^5 L^2 T^{-1}$.

Viscosity, structural

[fluid dynamics] $\eta = \eta_0 \kappa_{\text{visc}}^{n-1}$ where η_0 is a material constant or baseline viscosity (Newtonian), $\kappa_{\text{visc}} = v(r, t) / b$ is the shear velocity with $v(r, t)$ the flow velocity of a COUETTE FLOW and b the DISTANCE between the walls (e.g., thickness of the viscous layer), and n is an indicator for the type of viscous behavior, with $n = 1$ for Newtonian, $n < 1$ for pseudoplastic (SHEAR-THINNING FLUID) and $n > 1$ for dilatant (SHEAR-THICKENING FLUID), as introduced by Ostwald and De Waele (1924) (see Figure V.34).

Typical response of materials with various viscosity structures
to a step change in shear rate

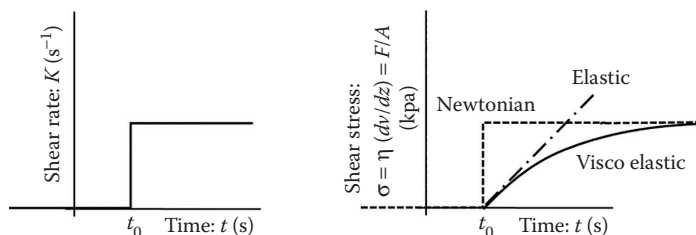


Figure V.34 Diagram illustrating the concept of structural viscosity.

Viscosity index

[fluid dynamics] See VISCOSITY.

Viscosity meter

[fluid dynamics, general] The viscosity of a flowing liquid can be determined from the flow: Q [m^3/s] as $Q = [\pi(P_2 - P_1)r^4] / 8\eta L$, where η is the VISCOSITY, L the length of the flow segment separating point 1 and 2 with pressures: P_i at the respective cross sections, and r the radius of the tube used to measure the flow. The viscosity is primarily determined by determining the time it takes for a fixed volume to pass through a segment of uniform tube.

Viscosity model

[biomedical, fluid dynamics] In flow DYNAMICS, the following FLUID characteristics can be defined: Newtonian: $\tau_s = \eta \dot{\gamma}$. Alternatively, for NON-NEWTONIAN FLUIDS—expressing the viscosity as a power function: $\eta = C \dot{\gamma}^{n'-1}$. The non-Newtonian behavior can be described for many different models: Pseudoplastic: $\tau_s = K \dot{\gamma}^n$ power function: ($n < 1$) $\{n' < 1\}$; Dilatant: $\tau = K \dot{\gamma}^n$ ($n > 1$) $\{n' > 1\}$; Bingham: $\tau_s = \tau_y + \eta \dot{\gamma}$; Casson: $\tau_s^{1/2} = \tau_0^{1/2} + \eta_c^{1/2} \dot{\gamma}^{1/2}$; Cross: the material stress σ_s is split for viscosity under low shear rate ($\dot{\gamma}$) η_0 , or viscosity under high shear rate η_∞ as a power function (power n) as $\sigma_s = \dot{\gamma} \left(\eta_\infty + (\eta_0 - \eta_\infty) / (1 + m_{Cr} \dot{\gamma}^n) \right)$, m_{Cr} a model constant; Herschel–Bulkley: $\tau = \tau_y + K \dot{\gamma}^n$; where τ_s is the shear stress, $\dot{\gamma}$ the shear rate, η the APPARENT VISCOSITY, K the consistency index for the medium, n is what may be best described as the “flow behavior index,” the subscript: c indicates a critical value or threshold (see Figure V.35).

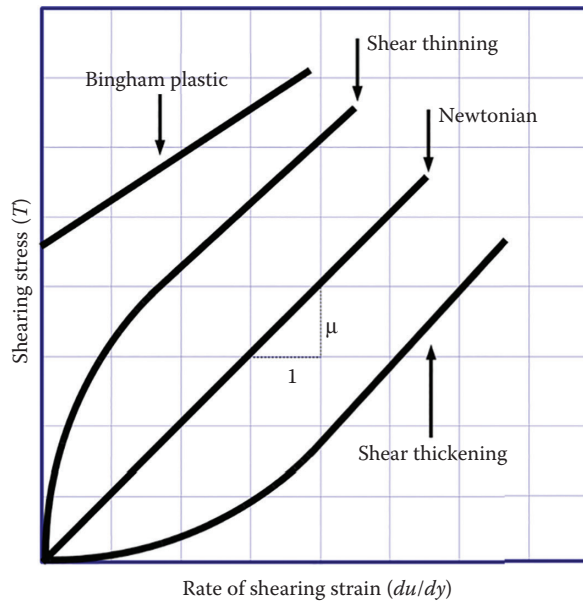


Figure V.35 Viscous models.

Viscosity of deformable spherical particles (η_{sph})

[fluid dynamics, general, nuclear] Spherical objects in SOLUTION that are forced into a spherical configuration by SURFACE TENSION will be compliant in contrast to rigid particles. The viscosity is defined by the FLUID viscosity of the droplets $\bar{\eta}$ and the material constant baseline Newtonian viscosity η_0 as $\eta_{sph} = \eta_0 \left(1 + c_1 \left[(1 + (5/2)(\bar{\eta}/\eta_0)) / (1 + (\bar{\eta}/\eta_0)) \right] \right)$, which also shows that for rigid droplets the fluid viscosity of the droplet becomes infinite ($\bar{\eta} \rightarrow \infty$) and the INTRINSIC VISCOSITY becomes $5/2$.

Viscous lubrication

[fluid dynamics] Flow BOUNDARY LAYER formed in close contact between a BUBBLE, red BLOOD CELL or solid object, and the WALL of the FLUID container.

Vision

[biomedical, chemical, optics] Conversion of electromagnetic RADIATION into electrical impulses by chemical conversion in the EYE. The eye is the anatomical component responsible for the electrochemical mechanism of vision. The electrical impulses are transmitted to the brain by neurons, which in turn generates a PERCEPTION with associated interpretation by the observer. In early Greek times the concept of EXTRAMISSIION, postulated by EUCLID (c. 325–270 BC), PTOLEMY (90–168 AD), and PLATO (427–347 BC) in various versions, was used to describe vision. It was proposed that the eye supposedly emits radiation, which is returned by objects in its path back to the eye to be recognized as vision. Extramission, however, does not account for not being able to see when no external LIGHT is provided. Two kinds of vision are recognized based on the biological and anatomical features next to the chemical processes involved. The two types of vision are intensity (grayscale) and COLOR vision. Intensity vision is achieved by the anatomical feature of the RODS, whereas the color vision is achieved through the CONES. Human vision and vision of specific species can be very different due to the specific requirements in the daily routine. For instance, birds of prey have a segmented vision which relies on two components of the RETINA to act as low and high RESOLUTION vision as described under ABBE CONDITION. Vision in the mammalian and reptilian eye is primarily controlled by accommodation of the CRYSTALLINE LENS. In insects the vision has an entirely different compound structure, constructed of a multitude of fixed APERTURES arranged in a honeycomb structure, providing a similar structure as multiple CAMERA-OBSCURA projections (*also see* SCOTOPIC and PHOTOPIC VISION).

- Trichromat: sees using all three colors (red/green/blue)
- Color vision problems
- Anomalous trichromat: reception of one pigment is reduced or misaligned (anomalous)
- Dichromat: only two of the three visual pigments exist—red, green, or blue is missing
- Protanomaly: reduced red sensitivity in an anomalous trichromat
- Deuteranomaly: reduced green sensitivity in an anomalous trichromat
- Protanopia: unable to receive first visual pigment (RED)

- Deuteranopia: unable to receive second visual pigment (green)
- Tritanopia: unable to receive third visual pigment (blue) (see Figure V.36)

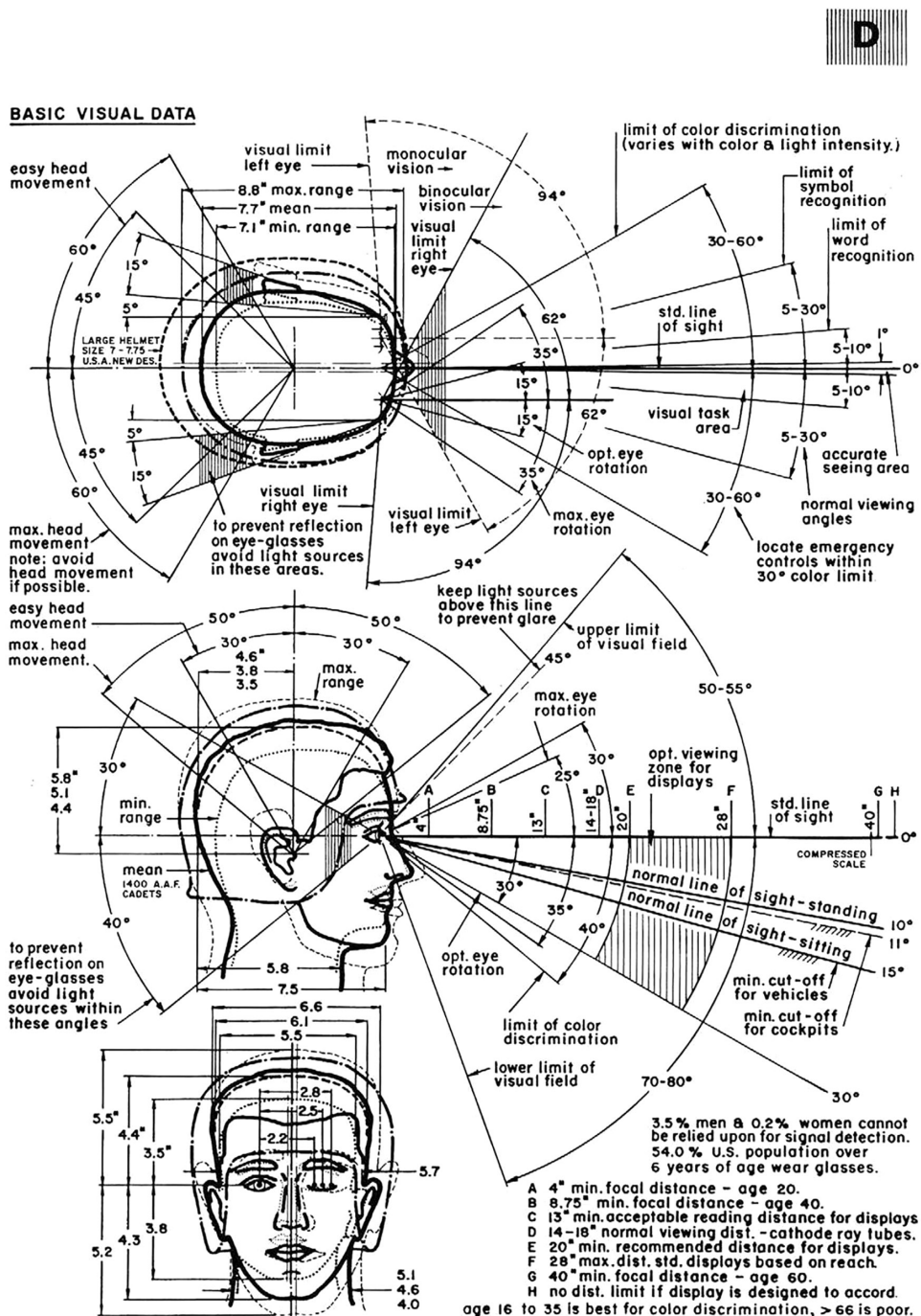


Figure V.36 Vision. (From Dreyfuss, H., *The Measure of Man; Human Factors in Design*, John Wiley & Sons, New York, 1959.)

Visual acuity

[biomedical, optics] The ability to see with high precision. One reference is with respect to the expression 20/20 vision for visual acuity. The statement 20/20 vision represents the ability to distinguish objects at a DISTANCE of 20 ft, set as the standard in the United States. Any deviations are expressed with different numbers; for instance, 20/100 vision reflect the fact that this person can see at 20 ft distance what a person with standard VISION can see at 100 ft distance. The statement 20/20 vision is no indication of perfect vision, just an indication of clarity; while vision clarity as high as 20/10 is possible for a normal person. An international standard for visual acuity is obtained with a reading chart, the Snellen chart (see [Figure V.37](#)).

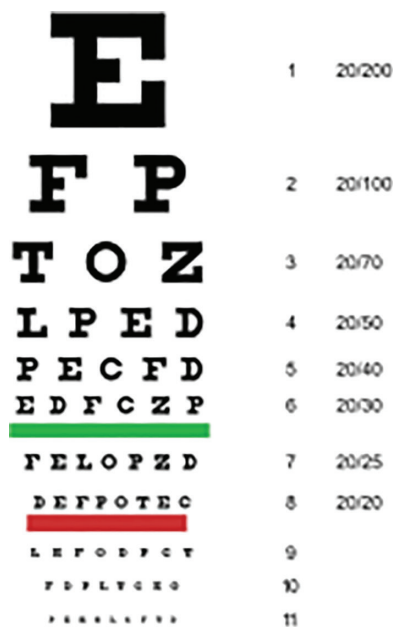


Figure V.37 Vision acuity scale. As set as standards by the International Council on Ophthalmology in 1984.

Vital capacity (VC)

[biomedical, fluid dynamics] The maximum potentially exhaled volume of gas from the lungs after the lungs are filled to TOTAL LUNG CAPACITY (TLC) during inspiration. Vital capacity and other TIDAL BREATHING parameter can be measured with a spirometer (*see* RESPIRATION).

Vitreous humor

[biomedical, optics] Gel-like substance between the backside of the CRYSTALLINE LENS and the RETINA in the HUMAN EYE. The vitreous humor has an index of refraction of $n_{\text{vitreous humor}} = 1.337$, keeping in mind that water has $n_{\text{H}_2\text{O}} = 1.331$, and AIR $n_{\text{air}} = 1.0001$. The vitreous humor also has a designated canal within the gel

that leads a confined path with a lower index of refraction directly to the FOVEA, the area of the retina with the highest density of RODS and CONES for high-resolution COLOR and brightness VISION (see [Figure V.38](#)).

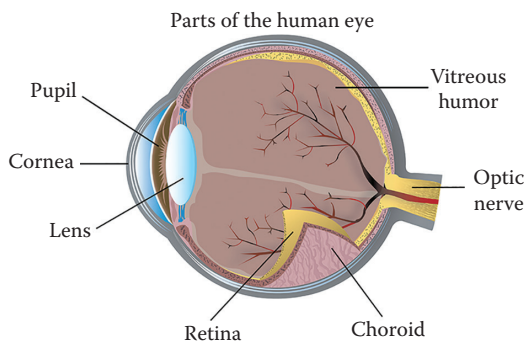


Figure V.38 Vitreous humor.

Voice

[biomedical, general] SOUND generated by the vocal cord of humans. Several factors determine the frequency content of the spoken sounds, specifically the difference between male and female voice spectrum is generally recognized, but is not defined absolute. A adult male bass voice can have an approximate frequency range from 65 to 400 Hz (starting at a “low-C” note), where an alto voice roughly ranges from 200 to 70 Hz, and a soprano spans in the range 261 to 1047 Hz ranging to a “high-C;” respectively for a female 261 to 1280 Hz. The adult female voice for general speech ranges generally from 165 to 255 Hz, while a female scream can reach 3000 Hz; whereas the male conversational voice is on average in the spectrum 85 to 155 Hz. Children may reach higher tones, up to 3500 Hz (see [Figure V.39](#)).

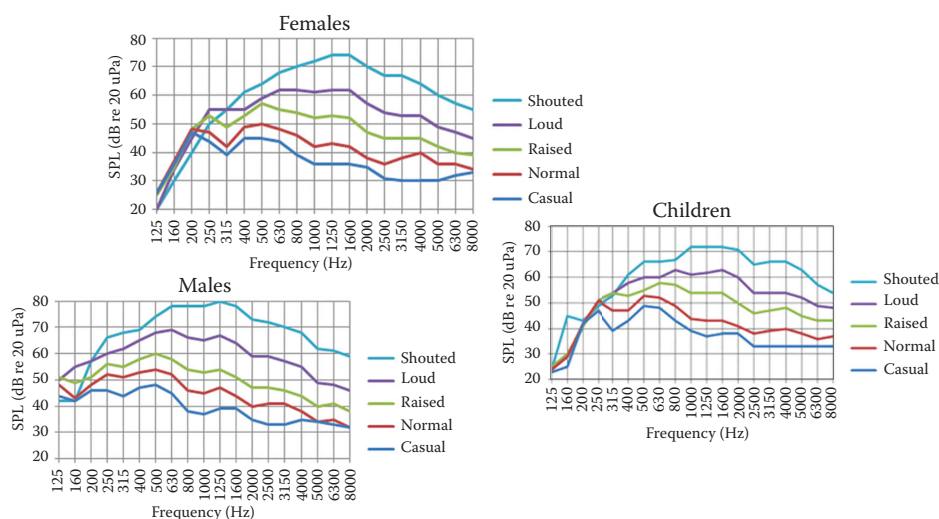


Figure V.39 Voice, as generated by the larynx, representative average spectral profile for man, woman, and child. (Courtesy of DPA Microphones, Alleroed, Denmark.)

Volcano

[acoustic, astrophysics, chemistry, electromagnetism, fluid dynamics, geophysics, mechanics, solid-state, thermodynamics] The study of the physical phenomena at the planet's surface due to eruption from the magma contained in the ASTHENOSPHERE when penetrating the lithospheric plates (see [Figure V.40](#)).

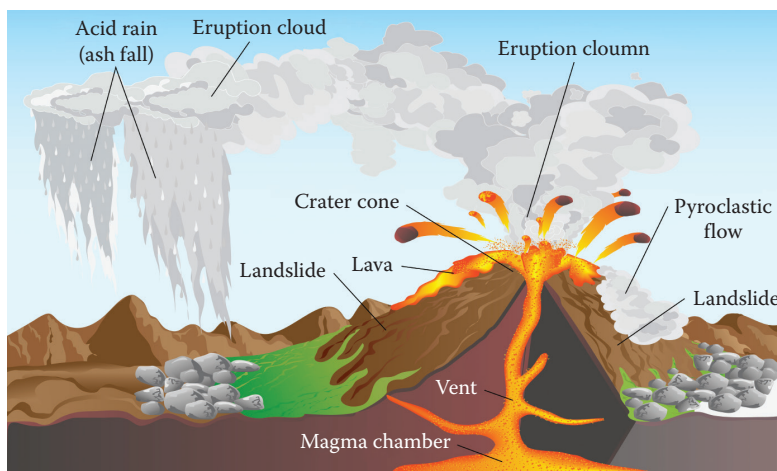


Figure V.40 Volcano; the erupting magma is hot enough to emit visible light under the Planck black-body radiation.

Volta, Alessandro Giuseppe Antonio Anastasio Gerolamo Umberto, Count (1745–1827)

[biomedical, electronics, energy, general] Italian scientist with a focus on PHYSICS, whose work was instrumental in the development of the BATTERY as well as the understanding of capacitance. Alessandro Volta was awarded the title Count by the Emperor Napoléon Bonaparte (1769–1821) in 1801 for his scientific contributions. Volta and his contemporary LUIGI GALVANI (1737–1789) had a close collaboration that formed the basis of several electrostatic and electrical current discoveries. Galvani was the inspiration to the formulation (1780) of the battery concept by Conte Alessandro Volta, as revealed in 1800 (see [Figure V.41](#)).



Figure V.41 Count Alessandro Giuseppe Antonio Anastasio Gerolamo Umberto Volta (1745–1827).

Voltage (V)

[electronics, general] Parameter used to define the electrical potential. Voltage is the electrical potential ENERGY per unit charge. Voltage difference between two POINT CHARGES is the electric field between the two locations multiplied by the separation of the two charges, expressed in units volt (V). The voltage between point A and point B is also equal to the work performed on an ELECTRIC CHARGE to move it from point A to point B, per unit charge (V_{AB}).

Voltaic pile

[general] Stack of alternating media designed by ALESSANDRA VOLTA (1745–1827) that provides a potential difference between the opposite ends of the stack. The pile was created out of disks made of zinc cardboard, silver and cardboard (i.e., cells), repeated (see [Figure V.42](#)).

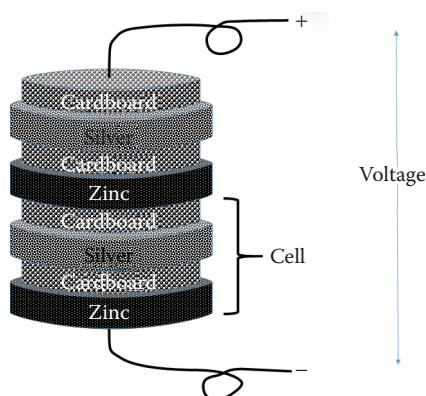


Figure V.42 Voltaic pile.

Voltaire

[general] Pseudonym of the writer and scientific activist from France: FRANÇOIS-MARIE D'AROUET (1694–1778). Voltaire used science to arouse the public awareness and to guard people against the unfounded tales of natural phenomena, specifically his fight against superstition. Although not a scientist himself, he used science to raise the standards of analytical thinking (see [Figure V.43](#)).

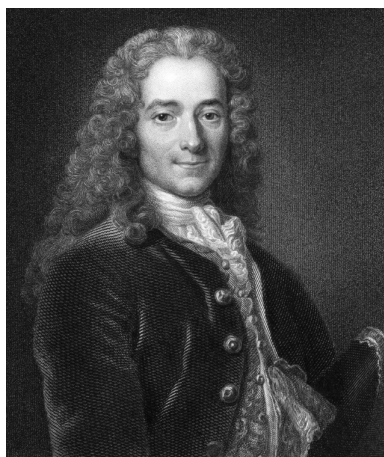


Figure V.43 Voltaire; François-Marie d'Arouet (1694–1778).

Voltmeter

[electromagnetism, general] Galvanometer in series with a resistor with the primary purpose of measuring the electrical potential between two points. The RESISTANCE is chosen to provide the idealized conditions of zero current, in order to prevent influencing the charge storage on the device being measured for voltage difference. Generally, the voltmeter is integrated in a multifunctional device that can measure current, voltage, and resistance called a multimeter (see [Figure V.44](#)).

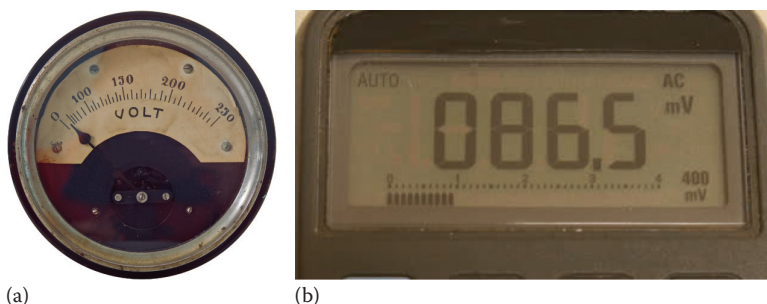


Figure V.44 Voltmeter: (a) analog and (b) digital.

Volume (V)

[general] Parameter with the primary meaning as the indication of three-dimensional containment. Reservoir with specific size, expressed in liter, m^3 in SI UNITS, or in gallon or FLUID ounces in the obsolete English (Imperial) unit system. Alternatively, the volume of SOUND is an indication of the AMPLITUDE of the acoustic WAVE, used for QUANTIFICATION of listening to audio (see [Figure V.45](#)).



Figure V.45 Volume measurement with calibrated flasks and beakers.

Volume charge density (ρ_e)

[general] The total charge ($Q = \sum q$) in a volume of medium divided by the respective volume (V): $\rho_e = Q/V$. In contrast, the charge can be spread over the surface of a medium, specifically a plate, but also for a CONDUCTOR all charge will be concentrated on the surface. The charge spread over a surface is expressed by surface density, respectively: σ_e . On a wire the charge density will be a line-charge density (one-dimensional), expressed as λ_e .

Von Fraunhofer, Joseph (1787–1826)

[optics] Scientist and physicist from the Prussian Empire (Germany) that was influential in optical discoveries. Joseph was born into a family of glassmakers, which led him to work on LENS development, making very accurate and proficient achromatic lenses. Based on his interests in OPTICS, Von Fraunhofer discovered the ATOMIC EMISSION SPECTRUM for the SUN in 1814, separating out more than 574 lines. Additional work by Fraunhofer was in the experimental and theoretical work on the diffraction from multiple thin slits, using closely spaced wires; DIFFRACTION GRATING. Josef von Fraunhofer is frequently referred to as “Fraunhofer.” (see [Figure V.46](#))



Figure V.46 Joseph von Fraunhofer (1787–1826).

Von Guericke, Otto (1602–1682)

[astronomy, general] Scientist, physicist, and engineer from Germany (Prussian Empire). The first static electricity charge generator was developed by Otto von Guericke in 1650. Additional work by Von Guericke was in. The VACUUM work by Von Guericke was performed on a system referred to as the Magdeburg hemispheres, two copper hemispheres with flanges attached on respective tips of the dome, and an outlet VALVE to provide the means to evacuate the dome. The flanges gave the hold to apply tensile force on both hemispheres. Von Guericke provided the foundation for modern METEOROLOGY, and worked on

ELECTROSTATICS as well. His electrostatic efforts provided one of the first documented devices to generate a substantial electrostatic charge (see [Figure V.47](#)).



Figure V.47 Otto Von Guericke (1602–1682), engraving after a portrait by Anselm van Hulle.

Von Helmholtz, Hermann Ludwig Ferdinand (1821–1894)

[biomedical, electrodynamics, energy, mathematics, thermodynamics] Physicist and mathematician from the Prussian Empire (Germany) (see **HELMHOLTZ, HERMANN LUDWIG FERDINAND VON**) (see [Figure V.48](#)).



Figure V.48 Hermann Ludwig Ferdinand von Helmholtz (1821–1894).

Von Kármán, Tódor (Theodore) (1881–1963)

[astrophysics, fluid dynamics] Physicist and mathematician from Hungary. Theodore von Kármán contributed to the theoretical description of vortices and TURBULENCE, next to his work in aerospace ENGINEERING. Von Kármán designed one of the first functioning helicopters in the early 1920s. Later in his career Von Kármán provided guidance to the design and development of rockets, guided missiles, and PROPULSION jets for fighter planes. Von Kármán's work in FLUID DYNAMICS has made significant contributions to the

understanding of boundary layers and turbulence phenomena; specifically the “KÁRMÁN VORTEX STREET” description (see [Figure V.49](#)).



Figure V.49 Theodore von Kármán (1881–1963). (Courtesy of United States Army, United States Army Scientific Advisory Board, Washington, DC, USA.)

Von Kármán vortex street

[fluid dynamics, general] See **KÁRMÁN EDDY CURRENT VORTEX STREET**. It is also known as “Kármán vortex street.” (see [Figure V.50](#))

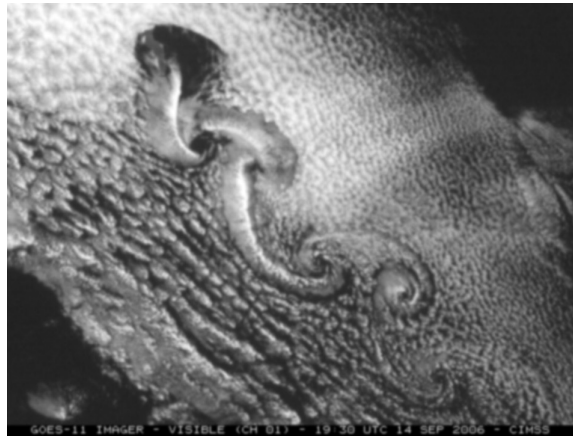


Figure V.50 Satellite image of von Kármán vortex street in the cloud cover, downwind from Guadalupe Island. (The Guadalupe island is located off the west coast of Baja, California). (Courtesy of University of Wisconsin, Madison, WI.)

Von Kleist, Ewald Jurgens (1700–1748)

[energy, general] Administrative clerk and engineer from Prussia (former greater German Empire) who discovered the mechanism of storing charge in a jar with LIQUID, the LEYDEN JAR. The charge storage was performed during his studies in Leiden (old Dutch vernacular: “Leyden”), hence the name (see [Figure V.51](#)).



Figure V.51 Ewald Jurgens von Kleist (1700–1748).

Von Laue, Max Theodor Felix (1879–1960)

[computational, electromagnetism, nuclear] Physicist from Germany. Max von Laue received the Nobel Prize in Physics for his X-RAY diffraction work (performed in 1912), and the ensuing understanding of crystal and LATTICE structure of atomic and molecular configurations. The lattice structure theory was supported by contributions from Sir WILLIAM LAWRENCE BRAGG (1890–1971) in 1913. Von Laue worked on crystallography, OPTICS, relativity, SUPERCONDUCTIVITY, and QUANTUM THEORY (see [Figure V.52](#)).



Figure V.52 Max Theodor Felix von Laue (1879–1960). (Courtesy of German Federal Archive [Deutsches Bundesarchiv], Koblenz, Germany.)

Von Laue's method

[computational, nuclear] Mathematical method based on the work of MAX THEODOR FELIX VON LAUE (1879–1960) describing electron and NEUTRON diffraction on atomic level, revealing the atomic and LATTICE structure of crystals and solid-state configurations. The Laue method provides a lattice description based on observations. The Laue method is based on the Miller index for lattice planes, using the lattice vector ($\vec{b}$), describing the plane spacing and orientation for the various lattice p -lanes, and the correlation with the respective LATTICE SPACING distance d_i , defined as $d_i = 1/|\vec{b}|$. The refraction of X-rays in a crystal is described by the Laue equation (based on the Bragg's law), in one dimension as $(AB - CD) = a \{ \cos(\alpha_n - \cos \alpha_0) \} = n_x \lambda$, where λ is the wavelength of the probing RADIATION. The diffraction pattern of the crystal resulting from exposure to a collimated narrow the X-RAY beam produced a pattern of spots which were supposedly correlated to the internal symmetry of the crystal; which was experimentally and theoretically confirmed (see Figure V.53).

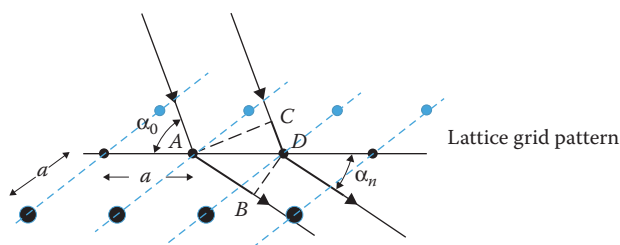


Figure V.53 Von Laue method diagram of action.

Von Leibniz, Gottfried Wilhelm

[general] See LEIBNIZ, GOTTFRIED WILHELM VON.

Von Lenard, Philipp Eduard Anton (Lénárd Fülöp Philipp Eduard Anton von Lenard) (1862–1947)

[atomic, nuclear] Scientist from Slovakia/Austria-Hungary, now Germany. Von Lenard's work revealed important details about the "cathode ray." Other work was with respect to the MECHANICS, that is, oscillations, of precipitated water droplets. His interests in PHOSPHORESCENCE and luminescence led him to artificially

generate RADIATION. Lenard was able to generate LUMINESCENCE using a CATHODE ray in a VACUUM tube lined with aluminum, his discovery of the “Lenard window.” (see [Figure V.54](#))



Figure V.54 Philipp Eduard Anton von Lenard (1862–1947), approximately in 1900. (Courtesy of VendégVáró archív, <http://lexikon.vendegvaro.utazom.com/lenard-fulop-philipp-e-a-von-lenard>.)

Von Mayer, Julius Robert (1814–1878)

[general, thermodynamics] Physicist, physician, and engineer from Prussia (Germany), one of the founding fathers of THERMODYNAMICS. Von Mayer described the law of the CONSERVATION OF ENERGY (the FIRST LAW OF THERMODYNAMICS), and formulated the vital chemical process as the primary source of ENERGY for any living creature as OXIDATION, both in 1842. Von Mayer also proposed the rudimentary concept of PHOTOSYNTHESIS. His conservation of energy statement was largely overlooked and is mainly attributed to JAMES JOULE (1818–1889) who made his proclamation 1 year after Julius von Mayer (see [Figure V.55](#)).



Figure V.55 Julius Robert von Mayer (1814–1878).

Vortex

[computational, fluid dynamics, mechanics, thermodynamics] Conglomeration of particles involved in rotational motion, primarily relating to fluids. A detailed theoretical description of the velocity DISPERSION

in rotational MOTION of a LIQUID was first provided by HERMAN VON HELMHOLTZ (1821–1894). Due to the complex three-dimensional velocity profile Helmholtz-introduced velocity profiles with respect to the axis of rotation (i.e., vortex line) as the following directional gradient components of the vorticity:

$\xi_V = (\partial w / \partial y) - (\partial v / \partial z)$; $\eta_V = (\partial u / \partial z) - (\partial w / \partial x)$; $\zeta_V = (\partial v / \partial x) - (\partial u / \partial y)$, in CARTESIAN COORDINATES

$u = -(\partial \phi / \partial x)$ is the velocity in the x -direction, $v = -(\partial \phi / \partial y)$ is the velocity in the y -direction, and

$w = -(\partial \phi / \partial z)$ is the velocity in the z -direction, with ϕ is the VELOCITY POTENTIAL. The vortex line is defined

as $(\partial x / \partial \xi_V) = (\partial y / \partial \eta_V) = (\partial z / \partial \zeta_V)$. In general, the rotation motion of a FLUID can be derived by solving:

$(P/\rho) + (1/2)q_*^2 + E_V = (\partial \phi / \partial t) + F_V(t)$, where P is the local pressure on a streamline, ρ the fluid density,

the resultant velocity in the vortex is defined by $q_* = \sqrt{u^2 + v^2 + w^2}$, $E_V = -\int P d(1/\rho)$ is the work performed

by a unit of fluid mass in response to the external pressure, and $F_V(t)$ is a time function (t) describing the

rotational characteristics. More accurately the vector potential with respect to two moving particles A and B

along the streamline can be derived from: $\left[\int_A^B ((P/\rho) + \Omega - (1/2)q_*^2) \right] = -(D/Dt) \int_A^B (u dx + v dy + w dz)$, where

Ω is the force potential resulting from all external forces involved in the movement of the particles in the

vortex with potential ENERGY: $PE = \iiint \Omega \rho dx dy dz$. Since the velocity potential is tied to the kinetic energy

the velocity potential can be linked to the force potential as $(P/\rho) = (\partial \phi / \partial t) - \Omega - (1/2)q_*^2 + F_V(t)$. The

velocity field distribution: $\vec{v}(\vec{r}_p)$ (i.e., vector potential) in the vortex can be derived based on the VORTICITY

$(\vec{\omega})$ as $\vec{v}(\vec{r}_p) = 1/4\pi \int_V (\vec{\omega}(\vec{Q}, t) \times \vec{r}_{pQ}) / r_{pQ}^3 dV_Q$, where $\vec{P}$ and $\vec{Q}$ are positions on the axis or rotation and at the

revolution trajectory in the plane of interest and $\vec{r}_{pQ} = \vec{r}_p - \vec{r}_Q$, respectively. Using the vorticity $(\vec{\omega}(\vec{r}, t))$, the

linear impulse (I) and angular impulse ($\mathbb{A}$) of a vortex within a VOLUME (V) at location $\vec{r}$ can be defined as

follows: $I = (1/2)\rho \int_V \vec{r} \times \vec{\omega}(\vec{r}, t) dV$, and $\mathbb{A} = -(1/2)\rho \int_V \vec{r}^2 \vec{\omega}(\vec{r}, t) dV$, where ρ is the local density of the

INCOMPRESSIBLE FLUID with no viscosity (i.e., inviscid) (see Figure V.56).

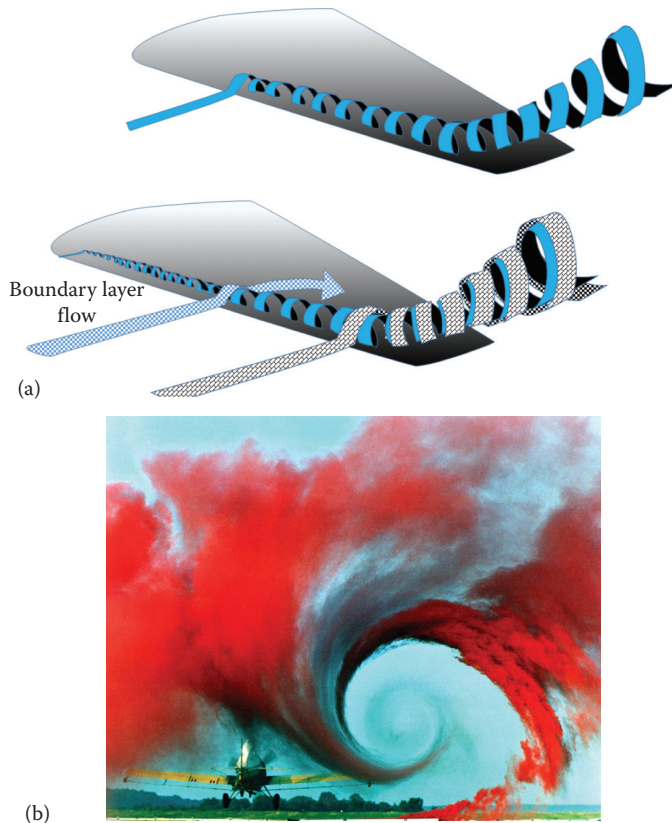


Figure V.56 Vortex: (a) formation of vortex on wing tip and (b) vortex behind wing of plane landing. (Courtesy of NASA Langley Research Center, Hampton, VA.)

Vortex, Kármán

[fluid dynamics] See **KÁRMÁN EDDY CURRENT VORTEX STREET**.

Vortex shedding

[computational, fluid dynamics, mechanics, thermodynamics] During the flow around a bluff body a KÁRMÁN VORTEX street is formed which has a pattern of flow that detaches from different locations on the circumference of the body to form a VORTEX pattern in the WAKE of the body. This detachment (shedding) occurs at a characteristic frequency. The shedding frequency is characterized by flow conditions and geometry. For a cylindrical object with flow condition defined by a Keulegan–Carpenter number equal to or greater than 20 ($K_C \geq 20$; *Note*: in this range the REYNOLDS NUMBER is relatively constant), the vortex-shedding frequency can be defined. This range categorizes QUASI-STEADY-STATE shedding conditions. For $K_C < 20$ the flow has fractional vortex shedding which does not allow for a steady frequency pattern to develop. The vortex-shedding frequency for $K_C \geq 20$ can be defined as $v_V = \text{Sr}(U_o/D)$, where Sr is the STROUHAL NUMBER (accounting for the SURFACE ROUGHNESS of the cylindrical object, e.g., PIPE), U_o the instantaneous flow velocity, and D the diameter of the cylindrical object in the flow path. In the case of flow around a prolate spheroid the unsteady Navier–Stokes equation for incompressible flow at a function of TIME (t) will need to be solved: $\nabla \cdot u = 0$ and $(\partial u / \partial t) + u \cdot \nabla u = -\nabla P + (1/\text{Re}_\infty) \nabla^2 u$, where ∇ is the Laplace operator, u is the flow velocity, P the pressure, Re_∞ the Reynolds number based on the free-stream flow velocity u_∞ , and d the diameter of the sphere. This spheroid vortex shedding frequency SOLUTION can only be obtained by NUMERICAL analysis.

Vorticity ($\vec{\omega}$)

[fluid dynamics] The degree of “rotation” experienced in flow VELOCITY ($\vec{v}$) as a function of location ($\vec{r}$) and TIME (t) expressed as $\vec{\omega}(\vec{r}, t) = \nabla \times \vec{v}(\vec{r}, t)$, which is the “curl” of the velocity at a given place (i.e., vector operator performing the rotation in infinitesimal steps of a three-dimensional vector field; curl: operator defining the rotation of the vector in infinitesimal steps, hence describing the projection of the vector upon all possible lines passing through the location in the three-dimensional space). The vorticity defines the CIRCULATION density derived from the flow velocity vector field. For an inviscid FLUID the rate of change in time for the VORTEX is described as $[d\vec{\omega}(\vec{r}, t)/dt] = \vec{\omega}(\vec{r}, t) \cdot \nabla \vec{v}(\vec{r}, t) + \nabla \times \vec{F}$, where $\vec{F}$ is the externally applied force density.

Voxel

[computational, fluid dynamics, imaging] Three-dimensional configuration with unique and uniform parameters and characteristics. This is the three-dimensional equivalent of the two-dimensional PIXEL in IMAGE reconstruction. The voxel is an ELEMENT in finite element analysis, used in computer simulations (e.g., Monte Carlo, finite element), image reconstruction and geometric deconvolution of real-time events in well-defined compartments. The three-dimensional representation of PET, computed-tomography, ULTRASOUND and other imaging techniques uses voxels as the smallest unique geometric unit in the visualization rendering process (see [Figure V.57](#)).

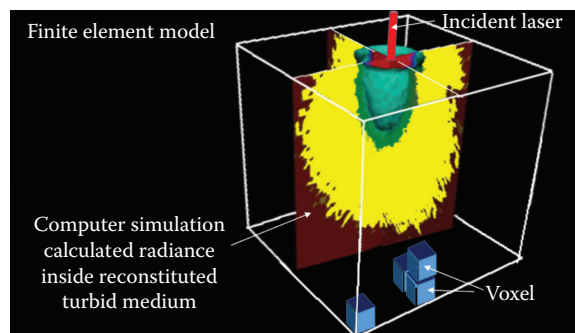


Figure V.57 Voxel.

V(z) inversion

[acoustics, imaging] SIGNAL processing technique used in acoustic microscope that allows for the extraction of material properties based on the power of the signal as a function of the location (position: “z;” the focal position) of the collection LENS. The spectral profile of the power profile of the acoustic imaging provides the means to derive the Young’s modulus. The ν -curve is a graphical deduction from the power losses per phase in a vector analysis of the Rayleigh wave velocities. The ν -inversion extracts the material properties based on ν -curves and applying PERTURBATION THEORY to the representation.



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Wake

[fluid dynamics] Vortices where the BOUNDARY LAYER of a flow detaches from the fixed surface. This phenomenon is more pronounced when the flow separates around the back side of a symmetric body totally submerged, reducing it to a two-dimensional flow such as a symmetric round pillar or a stick sunken into a solid foundation. This process becomes increasingly noticeable with an ascending REYNOLDS NUMBER, separation at the 180° point starts in the approximate range $2 < Re < 30$, depending on the boundary conditions. When the Reynolds number comes in the range $10^2 < Re < 10^5$, separation occurs before the midway point of the bluff rounded object, mainly before the 80° angle on the curved surface of the rod, measured from the centerline with the rod. This detachment generates KÁRMÁN EDDY CURRENT vortices (see [Figure W.1](#)).



Figure W.1 Wake.

Walecka, John Dirk (1932–)

[nuclear, quantum] Nuclear physicist from the United States. Walecka is known for his work on QUANTUM THEORY, specifically for many particles. John Walecka led the electron accelerator research at CEBAF (Continuous Electron Beam Accelerator Facility in Newport News), Virginia (see [Figure W.2](#)).

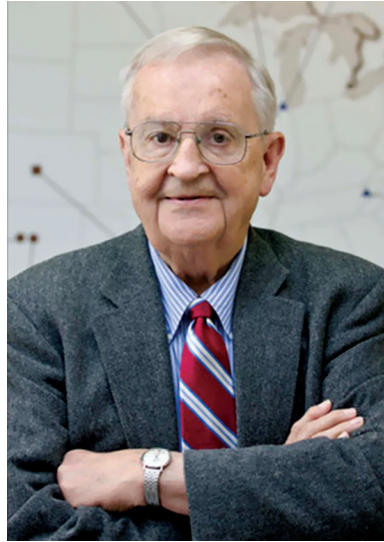


Figure W.2 John Dirk Walecka (1932–). (Courtesy of Jefferson Lab, Newport News, VA; the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility; U.S. Department of Energy; College of William and Mary, Williamsburg, VA.)

Wall

[biomedical, fluid dynamics, general, mechanics] Solid structure, mechanical separating structure, specifically with respect to objects or fluids in MOTION. The wall of a flow system determines the flow boundary conditions and flow-separation parameters. In biological context, a wall can have COMPLIANCE, such as the arterial wall, which stretches to accommodate the periodic in-flow with a high down-stream impedance (i.e., the vessel wall). The biological wall is different from many structural or industrial wall structures in the fact that it also provides a mechanism for osmotic DIFFUSION through the wall, well known as the diffusion of oxygen and carbon dioxide in the alveolar wall and the CAPILLARY wall of the lung organ structure. Generally walls are rigid and are designed mechanically to perform a specific function with thresholds for stability and durability. The wall of a confinement for a hydroelectric plant can burst when the security thresholds set as acceptable limits under design are exceeded. PIPE walls are generally made with metallic or POLYMER compounds, which can DECAY in strength over time and require frequent quality

control inspections to identify hairline cracks, which may propagate and generate conditions where the pipe may break. The process of crack propagation is an elaborate and complex procedure (see Figure W.3).

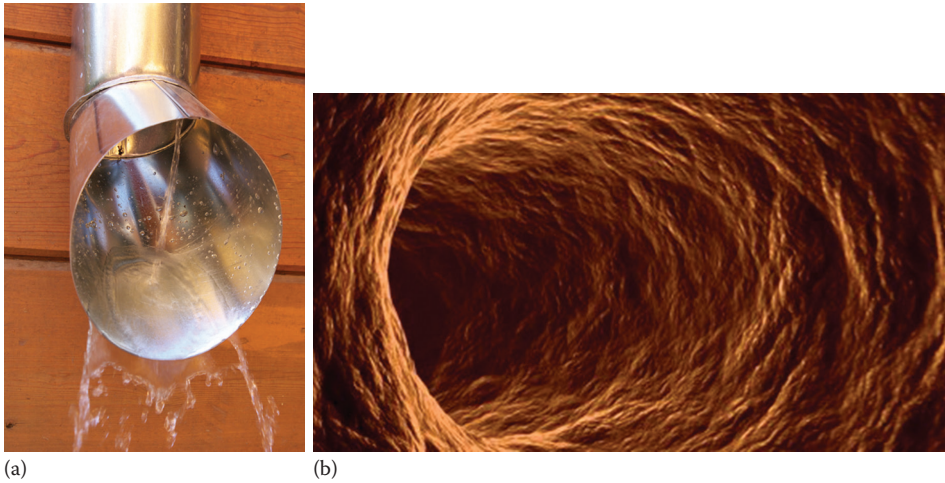


Figure W.3 (a) Wall, rigid drain pipe and compliant blood vessel (b) with an uneven surface structure.

Wall attachment phenomenon

[fluid dynamics] Fluid flow in close proximity to a **WALL** will form a **BOUNDARY LAYER** where the **FLUID** may attach to the wall and form a thin boundary layer in which there is no flow, that is, flow velocity is zero. The boundary layer can effectively generate the conditions to sustain the flow of the fluid with minimal friction (viscosity effects). Flow bordering a wall can result in detachment that results in turbulent pocket formation (the Coandă effect). Under Navier–Stokes dominated flow conditions, a boundary layer is formed with a thickness that is a function of the flow velocity (v) and the time constant (t') associated with the flow (respectively, periodic or continuous), defined as $\delta_b = \sqrt{vt'}$. At a low **REYNOLDS NUMBER** ($Re < 1$), the flow will not separate due to superior viscous behavior over inertial effects, maintaining a **LAMINAR FLOW** around an object. Certain sports ball designs use **SURFACE ROUGHNESS** to influence the boundary layer behavior and promote an early transition from a laminar to a turbulent flow. These ball games rely on operating in a Reynolds number range that is near the “minimum” of the “**DRAW COEFFICIENT**” ($C_d = F_d / (1/2)\rho v^2 A$, where F_d is the **FRICTION** of flow, the drag force, ρ density, and A the contact surface area) versus Reynolds number (Re) curve. Under these conditions, the drag will be lowest (*also see BOUNDARY LAYER*) (see Figure W.4).

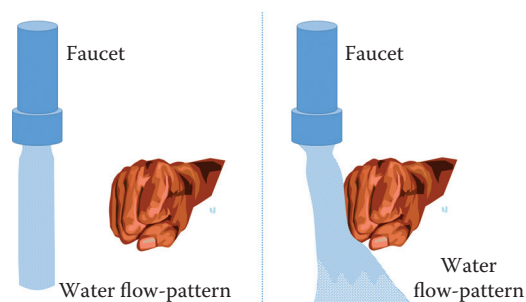


Figure W.4 Wall attachment phenomenon.

Wall factor 1 ($K_2 = 2(d_{PV}/D_C)$)

[fluid dynamics] Ratio of the sphere diameter to the column diameter for a ball falling down a LIQUID column, where d_{PV} is the sphere diameter equivalent to the PARTICLE volume, and D_C column diameter (see [Figure W.5](#)).

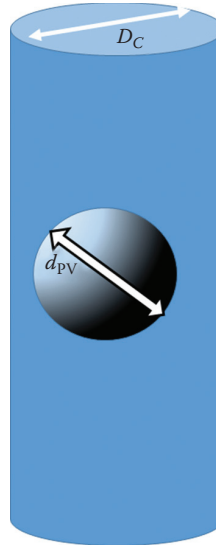


Figure W.5 Outline of the concept of Wall factor.

Wall factor 2 ($K_3 = (d_{PV}/D_C)(Z/D_C)$)

[fluid dynamics] Ratio of the sphere diameter to the column diameter for a ball falling down a LIQUID column multiplied by the relative SURFACE ROUGHNESS expressed as the size of the sediment (the bed height Z) over the flow diameter, where d_{PV} is the sphere diameter equivalent with the PARTICLE volume, and D_C is column diameter.

Wallis, John (1616–1703)

[general] Mathematician from Great Britain, involved in the scientific analysis of collisions. Wallis has one of the first documented applications of conservation of momentum, published in 1663. John Wallis formulated a method to solve for spatial indivisibles by means of interpolation (see [Figure W.6](#)).



Figure W.6 John Wallis (1616–1703) painted by Sir Godfrey Kneller. (Courtesy of The Wallis Project, University of Oxford, UK.)

Wall-tracing method

[fluid dynamics] Mechanism for visualization in close proximity to the WALL of flow, either by tufts or release of dye or BUBBLES. The wall-tracing method yields insights into attachment and detachment of flow at the BOUNDARY LAYER, flow velocity direction, and transition layers. One of several mechanism available to visualize flow patterns. Other techniques available are smoke lines, BIREFRINGENCE, wall tufts, bubble, dye, surface powder, schlieren, and PARTICLE suspension (equal density to the FLUID). These methods can elucidate four concepts: (1) streamlines, (2) timelines, (3) pathlines, and (4) streaklines. Streamlines are indicators of the flow-velocity vector, tangent to the flow direction. Timelines provide an instantaneous snapshot of the flow pattern of the mechanism used for visualization. Pathlines follow individual particles over a specific time interval. Streaklines yield information about a range of identifying units for a locus (single point) in the flow over a specific interval of time. The flow visualization techniques can be classified based on the mechanism of action as optical (Schlieren, shadow, birefringence, etc.), marker (SOLUTE, bubble, etc.), or mechanical (tufts, surface release, etc.) (see [Figure W.7](#)).



Figure W.7 Wall-tracing method for fluid flow.

Walton, Ernest Thomas Sinton (1903–1995)

[atomic, nuclear] Scientist from Ireland, primarily known for his work on PARTICLE ACCELERATOR technology to enhance the efficacy of nuclear interactions (the Cockcroft–Walton accelerator). The work of Ernest Walton was different from the earlier efforts by ERNEST RUTHERFORD (1871–1937) using helium ions (ALPHA PARTICLES) and were based on PROTON interaction under an applied force resulting from an external electric field in 1932. Ernest Walton and the British physicist John Cockcroft (1897–1967) received in 1951 the Nobel Prize in Physics for their combined effort on the particle accelerator (see [Figure W.8](#)).



Figure W.8 Ernest Thomas Sinton Walton (1903–1995).

Water (H₂O)

[biomedical, chemical, fluid dynamics, general] CHEMICAL COMPOUND consisting of hydrogen and oxygen in a two to one ratio, joined by covalent bonds. The water molecule is shaped in the form of a V, but spread out at an ANGLE between the O–H bonds of approximately 104.5°. The “lob-sided” configuration provides the platform for the polarity of the water MOLECULE. Water is one of the most abundant substances on the EARTH, covering more than 70% of the earth’s surface area. Water is an essential medium to sustain biological life-forms, the HUMAN BODY for instance consists of approximately 59% of water. The constituents of water form one of the many options in the fuel-cell technology. Water forms the LIQUID phase of H₂O; alternatively ice is the solid phase and water VAPOR (steam) provides the GAS PHASE. Water forms the base for several scientific definitions of material properties. The SPECIFIC HEAT of water at standard pressure and temperature is $h_p = 1 \text{ cal/g}^\circ\text{C}$ (old units, but illustrating the historical value). The density of water under standard conditions is $\rho = 1 \text{ kg/L} = 1 \text{ g/cm}^3$. Note that water has the highest density at 4°C. The “acidity” of water has a PH of 7, on a scale ranging from 0 to 14; considered neutral. A pH lower than 7 indicates ACID (acidic) and a higher pH is “alkali” or base. Water has formed the foundation for the temperature scale in Celsius and Fahrenheit. On the CELSIUS SCALE, the FREEZING point yielding 0 (0°C), and the boiling point providing the landmark 100 (100°C) on the scale, as introduced by the Swedish scientist ANDERS CELSIUS (1701–1744) in 1742. The Celsius scale is the most widely used temperature scale, in comparison to the Fahrenheit scale devised by the Polish (Prussian) scientist GABRIEL DANIEL FAHRENHEIT (1686–1736) in 1724 based on the MELTING POINT of a mixture of ice, water, and ammonium chloride SALT (brine) at 0°F, versus the human body temperature (his wife’s oral temperature) as the second calibration point, providing 96°F at the time of the recordings (the Fahrenheit scale originally had a 12 base,

hence 96 as the body temperature, later adjusted for accuracy and on a decimal scale; currently the average human body temperature is set at 98.6°F). The Fahrenheit scale is primarily used only in the United States, whereas the rest of the world uses the Celsius scale for household and medical use. The Kelvin scale is technically the standard for temperature, as devised by the Scottish (British) scientist SIR WILLIAM THOMSON, LORD KELVIN (1824–1907) in 1854, which is not based on water (see [Figure W.9](#)).



Figure W.9 Water.

Water clock

[fluid dynamics] Next to the SUN dial, one of the oldest methods for measuring time. The water clock was first described based on historic finds dating back to the sixteenth century BC, whereas there are claims of Chinese water clocks as far back as 4000 BC. The Babylonian (city of Babylon; now part of Iraq [cultural and scientific center of Mesopotamia]), and later Greek, water clock was based on a set of bowls with fixed ORIFICE regulating the outflow rate (see [Figure W.10](#)).



Figure W.10 Modern day equivalent of the ancient water clock concept.

Water hammer

[fluid dynamics] Hydraulic shock produced when the flow of a liquid (GAS or fluid) is suddenly interrupted. The phenomenon was first described by Lorenzo Allievi. In water VAPOR flow, the condensation of steam due to EXPANSION and the resulting cooling can remain in flow but the increased density will carry additional momentum that will be released in another form of ENERGY when impacting a WALL of the tube system (curve, flange or valve). This phenomenon can be solved in two different ways, as an INCOMPRESSIBLE FLUID, or as a compressible fluid. When the kinetic event is gradual (e.g., slow valve closure), the FLUID may be considered as incompressible with the maximum pressure ($P_{\max}$) in the fluid-filled tube using the rigid column theory: $F_{\text{hammer}} = AP_{\max} = A((v_f L/t) + P_i)$, where P_i is the inlet pressure, v_f is the flow velocity, t is the VALVE closing time in seconds, and L is the PIPE length leading up to the event. Note that A is the area of the obstruction. Any sudden/instantaneous change in flow conditions or abrupt closure of the valve will incorporate the compressibility of the medium in flow primarily with respect to the role of the WAVE speed propagation. The force exerted by the fluid compartment in free flow is calculated by the JOUKOWSKY EQUATION, where the change in force yields: $\Delta F = (dP/dt)A_{\text{surface}} = \rho v_w (dv_f/dt)A_{\text{surface}}$, where v_w is the SPEED OF WAVE PROPAGATION in the fluid, ρ the density of the fluid, and v_f the velocity of flow on closure or impact on the surface area A_{surface} that equals the maximum force exerted since the impact force is initially zero (open) (see Figure W.11).

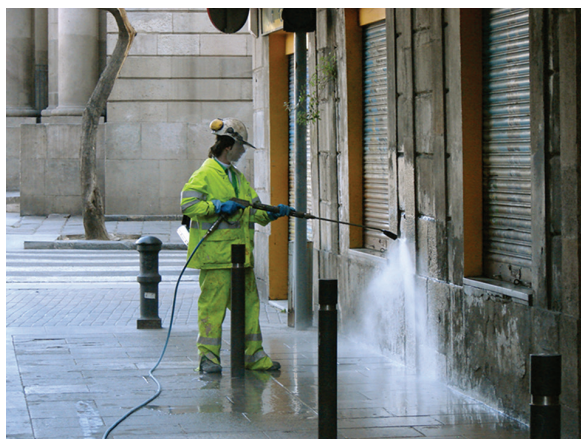


Figure W.11 Water hammer as the mechanism of action in a pressure-washer system.

Water reactor

[nuclear, thermodynamics] Modern NUCLEAR REACTOR with ordinary water as the MODERATOR under pressurized conditions. A separate CIRCULATION system with a LIQUID coolant transfers the ENERGY generated by the FISSION process to a third system that powers a steam TURBINE electrical GENERATOR (see NUCLEAR REACTOR).

Water wave

[electronics, general, mechanics] Water waves are generated because of the fact that the surface is disturbed by the shear stress force resulting from the wind with a component perpendicular to the normal to the water surface. There is a minimum wind speed of $v \geq 1.1$ m/s that needs to be exceeded to affect the surface. The flow of AIR over the water surface creates pressure gradients based on the Bernoulli principles that cause the surface to break out and allow the parallel component of the wind to apply a force directly

on the protruding ripples. Under uniform and continuous exposure over a significant area of water surface, the height of the surface elevation departing from equilibrium (b_s) will develop a FREQUENCY (ν) spectrum profile that is primarily a function of the wind velocity, expressed as $b_s(\nu) = A_w(g^2/\nu^5)\exp(-1.25[\nu_m/\nu]^4)$, where $A_w = 5.2 \times 10^{-6}$ is a constant, $\nu_m = 0.13 g/U_w$ is the frequency of the central peak of the spectrum, with U_w the wind velocity at 10 m above the water surface, and g the GRAVITATION acceleration. The length of the surface area minimally subjected to the surface wind shear stress is referred to as the fetch. Near the coast line with a wind blowing off-shore the fetch is limited, and both the constant (A_w) and central peak frequency (ν_m) become a function of the fetch. Due to the viscosity of the water, there is a nonlinearity in propagation (specifically nonlinear acceleration) where the short waves are damped more dramatically than long waves, resulting in long propagation distances for low-frequency waves, that is, swells (e.g., $\nu \sim 0.10$ Hz yields undisturbed waves over thousands of kilometers with little loss of ENERGY). Waves propagating in the opposite direction of a local water current will concurrently grow in height. Due to various conditions, the waves generated in one direction will not necessarily remain confined and generally will spread out angularly over the surface (θ , with respect to the original path of the wind or the primary WAVE direction) similar to a Lambertian angular distribution of LIGHT emitted from a surface approximated by the following mathematical formulation: $b_s(\nu, \theta) = b_s(\nu)(2/\pi)\cos^2 \theta$; $\theta \leq (\pi/2)$ and $b_s(\nu, \theta) = 0$; $\theta > (\pi/2)$ (see TROCHOIDAL WAVE; also see SURFACE WAVE, CAPILLARY WAVES, SURFACE WAVES, TIDAL WAVES, and WAVE) (see Figure W.12).

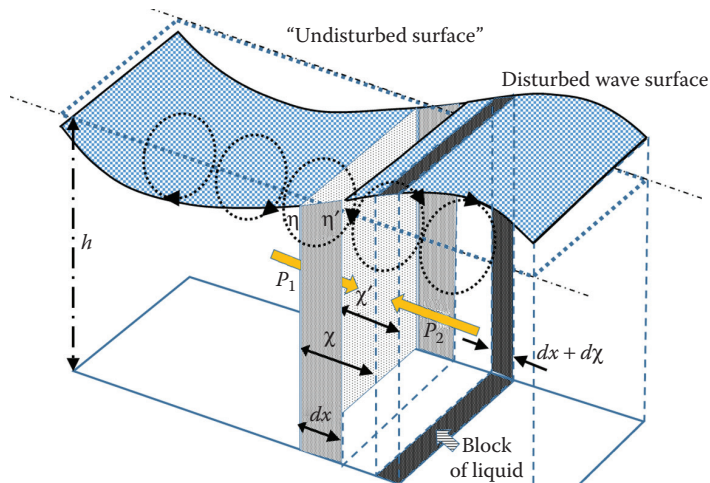


Figure W.12 Water wave.

Water wheel, power

[fluid dynamics] Consider a centrifugal blade-pump. The TORQUE (T) applied to the scoops is directly proportional to the force resulting from the FLUID between sections A_1 and A_2 , expressed as $T = m(r_2 v_2 \cos \alpha_2 - r_1 v_1 \cos \alpha_1)$, where α_i is the ANGLE with the reference frame with regard to the absolute velocity vectors u_1 and u_2 respectively, r_i the respective radii at the inner (1) and outer (2) area of the scoop with mass flow rate m along the blade. In this way, the torque on the impeller shaft can be derived from the states of

the fluids, respectively the velocities on the inlet and the outlet relative to the impeller. Combining the ANGULAR VELOCITY (ω) of the impeller with the torque yields the POWER (P) to the shaft as $P = T\omega$ (see [Figure W.13](#)).

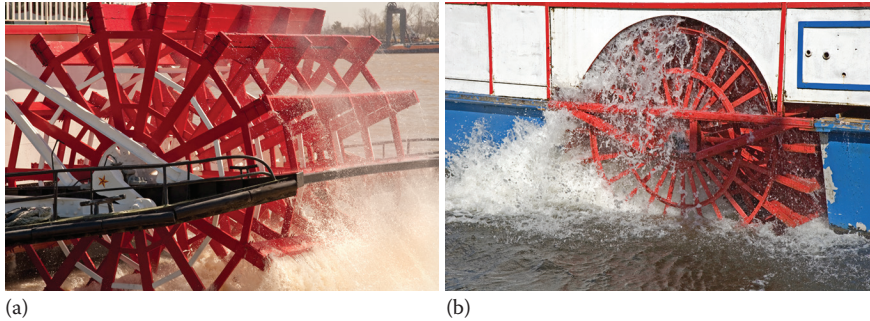


Figure W.13 (a) Water wheel; water wheel used to generate power, and water wheel as a mechanism of propulsion in the shape of a river boat paddle wheel (b).

Waterspout

[fluid dynamics, geophysics, meteorology] Updraft of water from a large water reservoir (lake, ocean), under an ATMOSPHERIC PRESSURE VORTEX. The pressure VORTEX is the result of the merging of two or more atmospheric pressure systems, generating a relatively small, confined rotational flow of AIR (air flowing from high- to low-pressure systems). The greatest ACTIVITY for water spout formation is over the Florida Keys in Florida. Larger waterspout contains more kinetic ENERGY and subsequently have a longer life-time. Waterspouts on the northern hemisphere generally rotate counter clockwise and on the southern hemisphere clockwise, due to the influence of the Coriolis forces. Occasionally the rotation will be clockwise on the northern hemisphere, as a result of the prevailing climatological conditions. Water VAPOR condensation provides an additional source of energy that fuels the TORNADO/waterspout mechanism of action (see [Figure W.14](#)).



Figure W.14 Waterspout.

Watson, James Dewey (1928–)

[general] Biologist (specialty: microbiology) and zoologist from the United States. James Watson and the scientist from Great Britain FRANCIS HARRY COMPTON CRICK (1916–2004) published the discovery of the double helix configuration of DNA in 1953, which makes up the human biological characteristics. Together with the third person, the physicist and biologist from New Zealand, MAURICE HUGH FREDERICK WILKINS (1916–2004), they received the Nobel Prize in Physiology/Medicine for their discovery in 1962 (see [Figure W.15](#)).

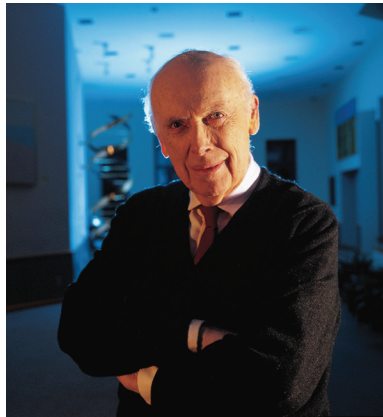


Figure W.15 James Dewey Watson [general], (1928–). (Courtesy of National Institutes of Health (NIH), Bethesda, MD.)

Watt, James (1736–1819)

[general] Scottish mechanical engineer and instrument maker by training, initially associated with the University of Glasgow. Watt never obtained the master title and was forced to seek employment outside the instrument maker guild's role of influence. He was a major contributor to developmental improvements to the recently introduced steam ENGINE developed by Thomas Newcomen in the early stages of the industrial revolution. At the AGE of 36, he partnered with Matthew Boulton to manufacture steam engines. His steam engine work inspired the development of the unit of power, the horse power (hp), later renamed after him as a credit to his contributions in the refinements to the steam engine (see [Figure W.16](#)).

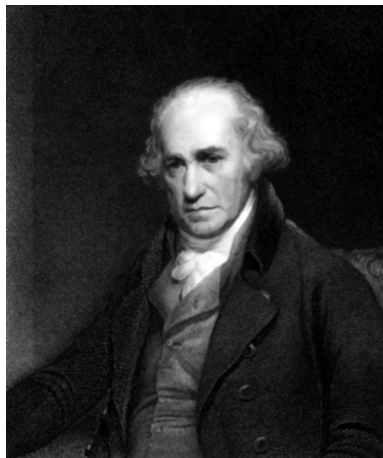


Figure W.16 James Watt (1736–1819). (Courtesy of C. E. Wagstaff.)

Watt (W)

[general] The unit of power introduced by JAMES WATT in 1783, the horse power (hp), was derived from the fact that by general observation a horse walking at 2.5 miles per hour could consistently pull 150 lb of mass, but is currently officially replaced by the watt (W) as a unit for power; $1 \text{ hp} = 550 \text{ ft}(\text{lb}/\text{s}) = 746 \text{ W} = 0.746 \text{ kW}$. The watt is also defined as ENERGY (i.e., joule) per SECOND: ($1 \text{ W} = 1 \text{ J/s}$).

Wave

[electronics, fluid dynamics, general, mechanics] Periodic phenomenon with specific, unique spatial or temporal profile, generally propagating with a velocity that is defined by both the WAVE mechanism and the local conditions for the medium of propagation. A wave is an ENERGY fluctuation with a fixed frequency, operating around a general EQUILIBRIUM STATE. Mechanical waves rely on the displacement of a medium, either as a transverse or LONGITUDINAL WAVE; TRANSVERSE WAVES appear in surfaces or structures (rope), whereas longitudinal waves are for instance pressure waves. A wave is part of an OSCILLATION. Mechanical waves are for instance water waves, SEISMIC shear waves (s-waves; part of EARTHQUAKE), waves in a rope, as well as sound waves. Another wave action is found in electromagnetic waves. Depending on the mechanism of action for the wave formation and propagation, the wave will conform to either then MECHANICAL WAVE equation, expressed in a one-dimensional format for a wave with displacement u traveling in the x -direction with velocity v as a function of time (t): $(1/v^2)(\partial^2 u / \partial t^2) = (\partial^2 u / \partial x^2)$; or the electromagnetic MAXWELL EQUATIONS. The general SOLUTION to the WAVE EQUATION travels in two opposite directions and has the format: $u(x, t) = u_0 \exp(\pm kx - \omega t + \phi)$, where $k = 2\pi/\lambda$ is the wavenumber, with λ the wavelength, and $\omega = 2\pi\nu$ the ANGULAR FREQUENCY, with ν the FREQUENCY (the period $[T]$ of the wave is linked to the frequency as $T = 1/\nu$), and ϕ is a location-specific phase shift. Individual waves are subject to the superposition principle, adding the respective local displacement/magnitude or electric/magnetic energy magnitude from all waves converging in one location. Another wave phenomenon, directly related to superposition is INTERFERENCE, where identical waves will depend on the superposition principle to provide PHASE information about the merging waves, specifically the respective difference in phase. A group of waves with various wavelengths traveling together propagate with the group velocity ($v_g = \partial\omega/\partial k|_{\omega=\omega'}$, with ω' the “central” frequency of the spectrum), whereas the individual waves travel with the PHASE VELOCITY ($v_p = \omega/k$). Group and phase velocities can be different, which results in DISPERSION. The MAGNITUDE of a wave phenomenon is generally expressed by means of the square of the maximum AMPLITUDE of the wave, the intensity; however, electromagnetic waves have two mechanisms that are at orthogonal directions and require a different means of quantifying the magnitude and use “fluence” or “radiance” as the parameter. A single waveform is identified by a sinusoidal expression, and in physical form will resemble a sinus function; under superposition, the addition of a broad range of frequencies can yield specific waveforms, for instance: sawtooth, square, or triangular. Electronically another phenomenon is introduced, the rectified wave, which has no negative deflection. A standing wave is the result of the superposition of two identical waves traveling under well-defined boundary conditions adding to a wave that does not migrate; the crests remain in single

respective locations. For an open tube, the crest/through (maximum displacement in either direction) will be at the opening (for instance an acoustic wave in a tube or the free end of a string) by definition, similarly for a closed tube (SOUND) the zero-displacement “node” (equilibrium-point) will be at the closed end WALL, or the attached part of the string. For electromagnetic waves, the direction of the electric field defines the POLARIZATION direction of the RADIATION. The flow of water from a faucet consists of a superposition of a multitude of waves, creating interference. The three-dimensional interference in the water flow will make the stream appear as turning throughout its flow process, or it will make the stream expand and contract, next to a multitude of other visible wave and fluid-dynamic phenomena (*also see BEAT FREQUENCY and AIR WAVES*). See TIDAL WAVES, TIDAL BORE, TROCHOIDAL WAVE, WATER WAVES, HARMONIC OSCILLATION, and VIBRATION (see Figure W.17).

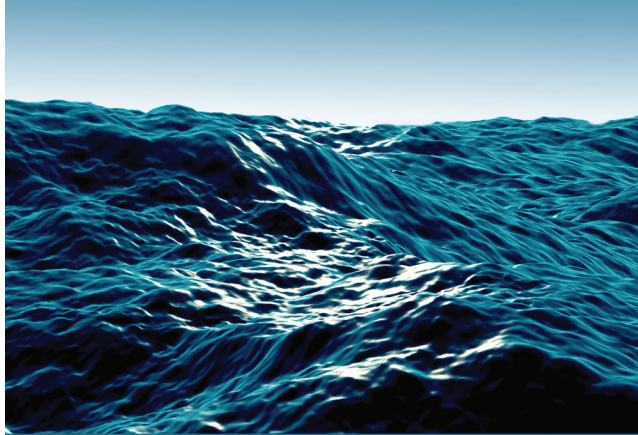


Figure W.17 Wave.

Wave dispersion

[acoustics, biomedical, biophysics, electromagnetism, engineering, fluid dynamics, general, geophysics, mechanics, optics, theoretical, ultrafast phenomenon] (syn.: crest, LIGHT, SOUND, surf, TIDAL WAVE, spatial domain fluctuations) {use: energy, imaging, spectroscopy} Wave propagation is controlled by various factors, such as liquid DENSITY (ρ) and discontinuities in the path. Wave dispersion is directly correlated to the definition of the GROUP VELOCITY OF WAVES: $v_g = d\omega/dk$. In GEOPHYSICS, the wave pattern produces a phenomenon called surf that is the result of the interrelation of the FREQUENCY (f) or WAVELENGTH (λ) (since: $f = v/\lambda$) and the average depth of the liquid level h_a , providing a dependency of the speed of propagation (v). The phase velocity of surface waves ($v_{p,s}$). The wave dispersion is caused by the phase velocity dependence on depth which in turn is also a function of wavelength. The phase velocity of SURFACE WAVES is gives as $v_{p,s} = \sqrt{((g\lambda/2\pi) + (2\pi T_s/\rho\lambda)) \tanh(2\pi h_a/\lambda)}$, where g is the GRAVITATIONAL ACCELERATION, T_s is the liquid surface tension in the liquid surface under disturbed equilibrium conditions, and ρ the liquid density. The higher order Fourier components will have a higher speed of propagation as a result of a nonlinearity in acceleration (*also see SURFACE WAVES*) and will thus “run away” from the lower frequencies, creating a breaking wave approaching the shore. Generally the phase velocity equation can be reduced based on the boundary conditions; for instance, for long waves in deep water, the PHASE VELOCITY ($v_{p,s}$) for GRAVITATIONAL WAVES reduces to $v_{p,s} = \sqrt{(g\lambda/2\pi)}$, where: $\omega = 2\pi/T =$ angular frequency $= 2\pi v$ and the wavenumber $k = 2\pi/\lambda$. MATERIAL DISPERSION: wavelength dependence on the REFRACTIVE INDEX (n). Wave GROUP VELOCITY (v_g) will depend on the material properties, that is, the (localized) index of refraction. When the group velocity is smaller than the phase velocity ($v_g < v_p$), there is normal dispersion since $(dn/d\omega) > 0$. When the group velocity is greater than the phase velocity ($v_g > v_p$), the propagation suffers from anomalous dispersion. The group velocity for longitudinal propagation related to material dispersion is described by filling in the parameter definitions in the equation for group velocity:

$v_g = d\omega/dk = c/[n + \omega(dn/d\omega)]$ revealing a dependence on the index of refraction of the medium, which may vary locally based on material properties and temperature effects (*also see* SURFACE WAVE, MASS–SPRING SYSTEM *and see* DISPERSION) (see Figure W.18).

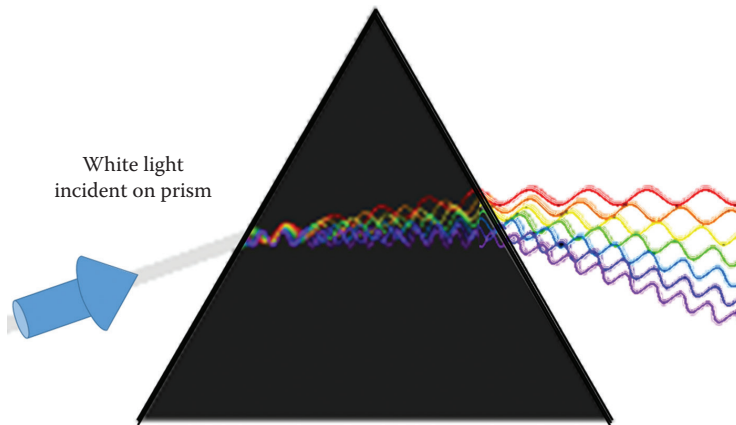


Figure W.18 Wave dispersion.

Wave energy

[electromagnetism, fluid dynamics, mechanics] The ENERGY of a WATER WAVE is proportional to the square of the height of the WAVE with respect to “sea level,” expressed as $U = (1/8)\rho g h^2$, where ρ is the LIQUID density and g is the local GRAVITATIONAL ACCELERATION. For electromagnetic waves, the energy is defined by the pointing vector as a function of the MAGNETIC FIELD strength and electric field strength: $\vec{S} = \sqrt{\epsilon_0 \mu_0} / 4\pi (\vec{E} \times \vec{B})$, units: W/m^2 , $c = \sqrt{\epsilon_0 \mu_0}$ the speed of LIGHT, ϵ_0 the DIELECTRIC permeability of VACUUM, and μ_0 the dielectric permittivity. Acoustic wave energy is expressed as $E = I/v_s = v^2 \rho = P_{ac}/v_s A$, where I is the intensity of the SOUND, v_s the speed of sound, P_{ac} the acoustic pressure at the crest, A the area on which the acoustic wave is impinging, v the PARTICLE velocity of the medium in the wave, and ρ the density of the medium in which the wave travels.

Wave equation

[mechanics, nuclear, quantum] Correlation between displacement as a function of location and elapsed time $\nabla^2 \Psi = -(1/v^2)(\partial^2 \Psi / \partial t^2)$, where ∇^2 is the Laplace operator (i.e., second-order differential operator in the n -dimensional EUCLIDEAN SPACE), the derivative in all relevant spatial coordinates, Ψ the function describing the phenomenon (e.g., electric or MAGNETIC FIELD, position), t the time, and v the propagation velocity of the phenomenon. For linear WAVE problems (small AMPLITUDE approximation), one can consider FOURIER SERIES decomposition of any complicated surface elevation pattern, and this leads to the study of the simple Fourier components of $\sin(\lambda x - ct)$ and $\cos(\lambda x - ct)$ (*also see* SCHRÖDINGER EQUATION).

Wave motion

[general, mechanics] The progressive disturbance propagated in a medium by a periodic vibration of the particles of the medium. Transverse wave motion is that in which the VIBRATION of the particles is perpendicular to the direction of propagation. Longitudinal wave motion is that in which the vibration of the particles is parallel to the direction of propagation (*see* WAVE).

Wave number (k)

[atomic, nuclear, optics] Abbreviated from “angular wave number,” defined as $k = 2\pi/\lambda$, with λ the wavelength of the electromagnetic RADIATION. The standard use of WAVE number identifies the spatial frequency of an OSCILLATION in the direction of travel (units, radians per meter). The historical significance of the wave number is the MAGNITUDE of the momentum of a wave in the direction of propagation $k = |\vec{k}| = |\vec{p}|/\hbar$ (where $\vec{p} = (E/c)\vec{e}_t = \hbar\nu/c$, with E representing the ENERGY, and $\vec{e}_t$ the direction of travel). In SPECTROSCOPY, the “ordinary wave number,” defined as $1/\lambda = k/2\pi = \nu/c$ ($c = 2.99792458 \times 10^8$ m/s being the speed of LIGHT, and ν the frequency), is used to specify spectral lines in cm^{-1} . The ordinary wave number spells out the number of wavelengths per DISTANCE, and is an expression of energy content.

Wave particle duality

[electromagnetism, nuclear, optics] The concept of LIGHT as a particle was proposed by SIR ISAAC NEWTON (1642–1727), expressed in 1704 in his work “Opticks” (with a rudimentary introduction in his “Principia” in 1687). This followed on CHRISTIAAN HUYGENS’s (1629–1695) proposition describing light as acting as a WAVE phenomenon in 1678. The particle concept was based on the ideas of ROBERT HOOKE (1635–1703). Newton’s particle theory was however based on the AETHER concept, but still holds true for pure ENERGY. Newton’s particle theory (the corpuscular theory of light) surpassed the wave theory and was generally accepted until THOMAS YOUNG (1773–1829) illustrated the concept of INTERFERENCE (e.g., DOUBLE-SLIT EXPERIMENT) in 1801, almost 100 years later. Meanwhile the experimental work by the scientists ARMAND HIPPOLYTE LOUIS FIZEAU (1819–1896) and JEAN BERNARD LÉON FOUCAULT (1819–1868), both from France, in 1850 revealed that the speed of light is different for different media, placing the PARTICLE definition in discredit, but it was still not abandoned. The theoretical work by the scientist from Scotland, Great Britain, JAMES CLERK MAXWELL (1831–1879), provided additional insights into the wave–particle duality, but did not fully convince the scientific community of the full extent of this concept. The particle model still held firm through the mid-1800, but the full duality was not fully understood until the 1920 experiments from the US physicist ARTHUR HOLLY COMPTON (1892–1962), who proved a particle phenomenon of photons: momentum. This provided the support to introduce the theory that matter and energy are interchangeable. In the same period, in 1923, the scientist and aristocrat PRINCE LOUIS VICTOR PIERRE RAMOND DE BROGLIE (1892–1987) from France, proposed that both MATTER and RADIATION have properties that equate to both a particle and a wave phenomenon (*also see* WAVELENGTH, DE BROGLIE).

Wave propagation speed

[biomedical, fluid dynamics, mechanics] The speed of propagation of waves can be described for various conditions; however, the basic definition is the rate of change in traversed DISTANCE: $v = dx/dt$, which is compounded by a host of material and WAVE characteristics. For mechanical waves, the following conditions can be distinguished: free medium (e.g., GAS), transverse wave in a stretched string, solids, and liquids. For a free medium, the speed of propagations is given as $v = v\lambda$, with v the frequency and λ the wavelength; string under tension: $v = \sqrt{F_t/m_L}$, with F_t the tensile force on the string and m the mass per unit length of the string; longitudinal density wave in LIQUID: $v = \sqrt{B/\rho}$ (also accounts for EARTHQUAKE mantle-wave propagation) with ρ the density and B the BULK MODULUS ($B = \Delta P/(\Delta V/V_0)$; pressure P and volume V); longitudinal density wave in gas: $v = \sqrt{\gamma P/\rho}$ with P the local gas pressure and γ a thermodynamic constant defined by the ratio of the SPECIFIC HEAT at constant pressure and at constant volume of the gas respectively ($\gamma = c_p/c_v$), which reduces to $v = \sqrt{P/\rho}$ for ideal gasses, taking the temperature dependence in consideration this becomes $v = v_0\sqrt{1 + (T_c/T_0)}$, where v_0 is the speed at the reference temperature ($T_0 = 0^\circ\text{C}$), and T_c the temperature of the IDEAL GAS ($^\circ\text{C}$); longitudinal compression wave in elastic and rigid solids: $v = \sqrt{Y/\rho}$ with Y the Young’s modulus. In terms of TRANSVERSE WAVES, the speed for electromagnetic radiation is

defined as $c = 1/\sqrt{\epsilon_0\mu_0}$, with ϵ_0 the (DIELECTRIC) permittivity and μ_0 the (dielectric) permeability, both in VACUUM. Also $v = c/v\lambda$, in vacuum; $v = v(\lambda_0/n) = c/n$, in the medium with n the local index of refraction, λ the wavelength (sub zero in vacuum).

Wavefront

[general] The graphical and physical connections between points that are in the same PHASE and time stamp of a WAVE pattern. For instance, the (cylindrically symmetric) curve connecting all points of a radially expanding wave resulting from a centrally located perturbation. For LIGHT, the wavefront may be composed of a range of frequencies; considering a single wavelength, the wavefront for a oscillating source will form a spherically symmetric shell that travels outward, for a laser the wavefront will be within the beam only and travel in unison across the diameter of the beam as part of the coherence conditions associated with laser light.

Wavefunction

[nuclear] The SOLUTION to the SCHRÖDINGER WAVE EQUATION in the DE BROGLIE WAVE model for a PARTICLE: $\Psi = \Psi(x, y, z, t) = \psi(x, y, z)\tau(t) = C_1\psi(x, y, z)e^{-iE/\hbar} = C_1\psi(x, y, z)e^{-i\omega t}$. The wavefunction has the following properties: (1) it must be single valued, (2) it must be continuous everywhere, and (3) the first respective partial derivatives must be continuous. The first partial derivatives for all components are directly related to the particle FLUX, that is, the quantity of particles intercepting per unit cross-sectional area at a given point in time (removing the time dependence).

Wavelength (λ)

[general, mechanics, solid-state] The DISTANCE traveled by a WAVE over the duration of one period (T) defined as $\lambda = vT = v/v = c/v$, with v the speed of propagation (c for light) and v the frequency of OSCILLATION. This temporal definition translates into the following spatial definition: the linear distance between any two similar points of two consecutive wave segments, for example, crest or trough, compression or expansion (i.e., rarefactions). The wavelength on a string is connected to the POTENTIAL ENERGY (PE_λ) and kinetic energy (KE_λ) in the string under the external force vibrating with AMPLITUDE A and ANGULAR FREQUENCY ($\omega = 2\pi v$), defined by the total energy stored in one wavelength: $E_\lambda = PE_\lambda + KE_\lambda = (1/2)m_L\omega^2 A^2\lambda$, where m_L is the mass per unit length of the string. This converts for a gas into: $E_\lambda = PE_\lambda + KE_\lambda = (1/2)\rho A(s_{\max}\omega)^2\lambda$, where ρ is the density of the gaseous medium and s the transverse displacement with amplitude: $s_{\max} = \Delta P_{\max}/\rho v\omega$, where $\Delta P_{\max}$ is the maximum deviation in pressure from equilibrium in the wave pattern (i.e., full compression or maximum rarefaction). A standing wave in a string or a tube with length L with both ends fixed/closed satisfies $n(\lambda/2) = L$, whereas when one of the ends is loose or open, this becomes: $n(\lambda/4) = L$, with n an integer >0 . In a disk, the process becomes more involved due to the various modes of standing waves in the area (e.g., drum, tambourine, xylophone, or cymbals). In case the membrane is symmetric with radius R , the standing waves need to satisfy the following conditions in cylindrical coordinates (due to symmetry; radial and angular, only two-dimensional): $\lambda^2 r^2 + [r^2/J_0(r(\alpha_{0n}/R))][d^2 J_0(r(\alpha_{0n}/R))/dr^2] + [r/J_0(r(\alpha_{0n}/R))][dJ_0(r(\alpha_{0n}/R))/dr] = \text{Constant} \Rightarrow m^2$, as well as $-(1/\Omega(\omega))(d^2 \Omega(\omega)/d\theta) = \text{Constant} \Rightarrow m^2$, where $J_0(r(\alpha_{0n}/R))$ is a Bessel function of order 0, r the radius of the membrane or plate, α_{0n} are roots of the Bessel function ($n = 1, 2, 3, \dots$), where $\lambda R \propto \alpha_{0n}$. With solutions to the angular equation $\Omega(\omega) = C_1 \cos m\theta + C_1 \sin m\theta$; C_i and m are constants. Light consisting of one single wavelength is considered monochromatic. The wavelength of the LIGHT emitted from an excited atomic state during the regrouping of electrons in the GROUND STATE is derived from the CONSERVATION OF ENERGY for the degenerating ATOM as $1/\lambda = (2\pi^2 k_0^2 e^4 m_e Z^2 / h^3 c) [(1/n_f^2) - (1/n_i^2)]$, where the electron decays from the initial

(n_i) energy level indicated by $E_n = (2\pi^2 k_0^2 e^4 m_e / h^2) [Z^2 / n_i^2]$, with k_0 the material constant for VACUUM ($k_0 = 1/4\pi\epsilon_0 = 8.98755179 \times 10^9$, ϵ_0 the permittivity of vacuum), e the electron charge, m_e , the electron mass, h PLANCK'S CONSTANT, and Z is the atomic number, or the number of protons. This expression holds for the Lyman, Balmer, and PASCHEN SERIES (see Figure W.19).

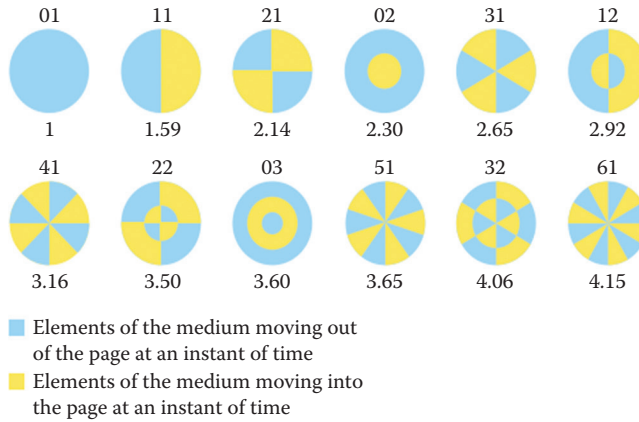


Figure W.19 Waveforms, in particular, modes of vibration for a circular thin sheet (e.g., drum skin, metal surface of a drum, and plastic area of the bottom of a bucket).

Wavelength, de Broglie

[atomic, nuclear] Based on the principle that every moving object has an associated DE BROGLIE WAVELENGTH λ_d tied to the momentum of a particle (p) to the inherent wavelength as $\lambda_d = h/p$, where h is PLANCK'S CONSTANT. For PROTON and neutron with $v \ll c$, this translates into $\lambda_d = 28.6/\sqrt{\text{KE}}$ (in MeV), units fm.

Weak force

[general] See WEAK INTERACTION (also see VAN DER WAALS FORCE).

Weak interaction

[atomic, computational, electromagnetism, general, quantum, theoretical] The weak interaction is described as a weak-interaction density distribution ($\mathcal{L}_W$) with the Lagrangian formulated in vectorial quantities as $\mathcal{L}_W = -(G/\sqrt{2}) J_\alpha^\dagger(x) J^\alpha(x)$, where $J^\alpha(x)$ represents the charge current, $J_\alpha^\dagger(x)$ the current equivalence for raising a charge in a transition such as from n -state to p -state, and G is the gravitational constant. The current is described by polar and axial terms as illustrated by the charged weak current for leptons: $J_{\text{lept}}^\alpha(x) = \bar{e} \gamma^\alpha (1 - \gamma_5) \nu_e + \bar{\mu} \gamma^\alpha (1 - \gamma_5) \nu_\mu + \bar{\tau} \gamma^\alpha (1 - \gamma_5) \nu_\tau$, where the leptons are $\bar{e}$ is the electron; ν_e the electron neutrino; $\bar{\mu}$ the MUON; ν_μ the muon neutrino and $\bar{\tau}$ the third charged LEPTON,

tau (the heaviest); and ν_τ the “third-lepton/tau” NEUTRINO, with $\gamma_\Sigma = i\gamma^0\gamma^1\gamma^2\gamma^3\gamma^4$ the current matrix with partial SCALAR terms (*also see FEYNMAN DIAGRAM*) (see [Figure W.20](#)).

Diagram of one of several potential weak interaction decay processes

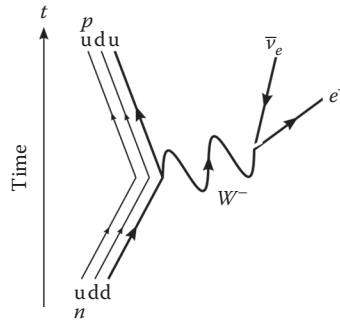


Figure W.20 Example of the concept of weak interaction.

Weber, Ernst Heinrich (1795–1878)

[biomedical, general] Physicist and scientist from Prussia (Germany). Apart from his work as a physician, Heinrich was interested in the scientific work of his brother WILHELM EDUARD WEBER (1804–1891), and together they described the culmination of two WAVE trains (sequence of wavefronts) to form a standing wave, which was made visible by mercury spread out over a sheet that was excited by acoustic (mechanical) waves from opposite sides. The mercury would under certain conditions pool in fixed locations, the nodes of the standing wave. Ernst Weber was interested in human locomotion and in particular the PHYSICS aspects of walking (see [Figure W.21](#)).



Figure W.21 Ernst Heinrich Weber (1795–1878). (Courtesy of Max Planck Institute for the History of Science, Berlin, Germany; lithographie von Rudolf Hoffmann, 1856; Österreichische Nationalbibliothek, Vienna; Austria.)

Weber, Wilhelm Eduard (1804–1891)

[general] Scientist and mathematician from Prussia (Germany). Wilhelm Weber was influenced by the work of his contemporary JOHANN FRIEDRICH PFAFF (1765–1825) as well as CARL FRIEDRICH GAUSS (Gauß; 1777–1855). Next to the acoustic work with his brother ERNST HEINRICH WEBER (1795–1878),

Wilhelm Weber worked on the MAGNETISM produced by an electric current and MAGNETIC radiation in general. Wilhelm Weber was responsible for designing a mechanism to quantify magnetic flux and the unit was named after his work performed in 1821, the weber. Additional work of Wilhelm Weber was in collaboration with Friedrich Gauss, which produced the first electromagnetic TELEGRAPH machine, used for long-distance communications. Wilhelm Weber also provided support for the observations by HIPPOLYTE FIZEAU (1819–1896) with his experimental conclusions in 1856, supporting the rudimentary formation of the WAVE–particle duality concept, as well as providing components for the theoretical efforts of JAMES CLERK MAXWELL (1831–1879). One of Wilhelm Weber’s pupils was the German mathematician Georg Friedrich Bernhard Riemann (1826–1866) (see [Figure W.22](#)).



Figure W.22 Wilhelm Eduard Weber (1804–1891). (Courtesy of Max Planck Institute for the History of Science, Berlin, Germany.)

Weber (Wb)

[general, electromagnetism] Unit of magnetic FLUX, $\text{Wb} = \text{Tesla}/\text{m}^2$, named after WILHELM EDUARD WEBER (1804–1891). The MAGNITUDE of magnetic flux is tied to the FARADAY LAW.

Weber number ($We = \text{Const}(\rho v^2 L / \sigma)$)

[fluid dynamics] Ratio of the inertial force to the SURFACE TENSION expressed as a dimensionless number, with the help of a dimensional constant, Const, where ρ is the density, v the velocity (for instance the velocity at impact on a surface where the droplet will experience the surface tension), L the characteristic length of the phenomenon (e.g., droplet diameter), and σ the surface tension. The Weber number is used to scale the phenomena in droplet formation, LIQUID jets, and momentum transfer in general. Under certain Weber number conditions, a water JET can be created, known as a WORTHINGTON JET.

Wedgwood, Josiah (1730–1795)

[general, solid-state] Material scientist (ceramist and potter) from Great Britain. The observations of Thomas Wedgwood as a manufacturer of fine china also made him interested in the physical aspects of the material treatment process. In 1792 Wedgwood described the thermal RADIATION associated with objects in a kiln, outlining the concepts of black-body radiation, well before the publication of the Kirchhoff

radiation law in 1859. GUSTAV KIRCHHOFF (1824–1887) added his own theoretical contributions and provided physical proof in 1861 (see [Figure W.23](#)).



Figure W.23 Josiah Wedgwood (1730–1795). (Courtesy of the photographer Stephen Betteridge.)

Weight (F_w)

[general] The force on a body resulting from a gravitational pull. Note that mass is a material property, but weight is a function of GRAVITATIONAL ACCELERATION.

Weinberg, Steven (1932–)

[general] Physicist from the United States, best known for his theoretical work on electroweak interaction. Steven Weinberg received the Nobel Prize in physics for his work on unified weak and electromagnetic interaction between ELEMENTARY PARTICLES with SHELDON LEE GLASHOW (1932–) and Abdus Salam (1926–1996) in 1979 (see [Figure W.24](#)).



Figure W.24 Steven Weinberg (1932–).

Weir, John B. de V. (?–?, twentieth century)

[biomedical, chemical, energy] Physiologist from Great Britain. Weir is most known for his analysis of ENERGY production based on oxygen (O_2) consumption in metabolic reactions, producing carbon dioxide (CO_2). Weir described the energy production independently for carbohydrates, proteins, and fatty constituents in three equations based on measurable quantities of chemical reagents fueling the reaction and products from the reaction. The resting energy equation is known as the WEIR EQUATION.

Weir equation

[biomedical, chemical] Heuristic formulation of the ENERGY expenditure ($E_{\text{metabolic}}$) from a protein and/or CARBOHYDRATE oxidation chemical reaction based on volumetric oxygen intake (V_{O_2}), volumetric carbon dioxide production (V_{CO_2}), as well as nitrogen volume equivalent released in the urine (M''_N), calculated per liter of oxygen. The Weir equation used nowadays combines the three influences and is expressed in Kcal/L as $E_{\text{metabolic}} = 3.941 + 1.106(V_{CO_2}/V_{O_2}) - 2.17(M''_N/V_{O_2})$. Derived by JOHN B. DE V. WEIR in 1948.

Weissenberg, Karl (1893–1976)

[fluid dynamics, imaging] Physicist and mathematician from Austria. Karl Weissenberg was involved in the definition of the X-RAY diffraction crystallography for which he devised a goniometer in addition to his work in RHEOLOGY (see [Figure W.25](#)).



Figure W.25 Karl Weissenberg (1893–1976).

Weissenberg number, ($Wi = t_f |\vec{v}|/D$)

[fluid dynamics] Dimensionless number used in VISCOELASTIC (i.e., non-Newtonian) flow as an indication of anisotropy resulting from flow deformation under a constant stress. The Weissenberg number is used to scale the deformation rate describing the ratio of the RELAXATION TIME to the flow timescale: $Wi \sim (t_r/t_f)$, where $t_f = \sqrt{(\text{tr}(\dot{\epsilon}))^2/2} = \text{tr}(\dot{\epsilon})/\sqrt{2}$ describes the flow timescale, tr denotes TRACE, $\vec{v}$ the flow velocity, and D the PIPE diameter or characteristic size of the phenomenon. The flow timescale is dependent on the strain rate $\dot{\epsilon}$,

which is defined by the flow velocity with the CAUCHY STRAIN TENSOR as $\dot{\epsilon} = \nabla \vec{v} + (\nabla \vec{v})^T$ with T the transposed matrix. For a steady low REYNOLDS NUMBER shear flow, the flow time factor is a function of the shear rate (γ): $t_f = 1/\gamma$ describing simple shear, whereas the flow timescale for extensional flow is $t_f = 1/\epsilon$, where ϵ is the extension rate or strain of the flow. The Weissenberg number becomes important when the flow timescale for the viscoelastic FLUID is less than the relaxation time (τ_r), and elastic effects become dominant. The Weissenberg number is closely related to the DEBORAH NUMBER ($De = t_f |\vec{v}|/L = Wi(D/L)$), with L the length of the phenomenon or tube length), whereas the Deborah number refers to a nonconstant stretch.

Weisskopf, Victor Frederick (1908–2002)

[atomic, computational, general, nuclear] Physicist from Austria. Weisskopf was part of the MANHATTAN PROJECT team. Weisskopf contributed to the development of the QUANTUM THEORY and worked on the basic understanding of the ENERGY structure of the atomic NUCLEUS. Weisskopf also contributed to the calculation of the LAMB SHIFT (see Figure W.26).

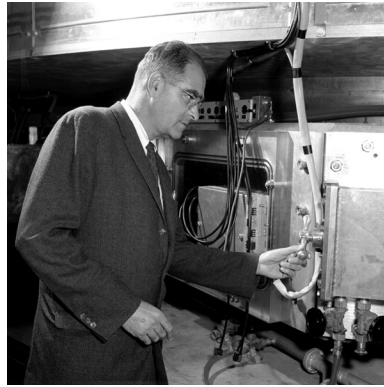


Figure W.26 Victor Frederick Weisskopf (1908–2002). (Courtesy and copyright CERN®, Conseil Européen pour la Recherche Nucléaire [European Laboratory for Particle Physics], Geneva, Switzerland.)

Weisskopf half-life

[atomic] Theoretical estimation for the single ($_{sp}$) gamma photon (γ) HALF-LIFE ($\tau_{1/2}$) for either nuclear electric transitions or MAGNETIC transitions. The PROBABILITY of transition within a certain time frame is expressed for either electric (EL) or magnetic (ML) DECAY phenomena as $\tau_{1/2}(\gamma)(EL)_{sp} = [\ln(2) L \{ (2L+1)!! \}^2 \hbar] / [2(L+1) e^2 R^{2L}] [(3+L)/3]^2 (\hbar c / E_\gamma)^{2L+1}$ and $\tau_{1/2}(\gamma)(ML)_{sp} = [\ln(2) L \{ (2L+1)!! \}^2 \hbar] / [80(L+1) \mu_N^2 R^{2L-2}] [(3+L)/3]^2 (\hbar c / E_\gamma)^{2L+1}$ respectively, where $\hbar = h/2\pi$ with PLANCK'S CONSTANT $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$, $R = 1.2 \times 10^{-13} \text{ A}^{1/3} \text{ cm}$ a constant, which is linked to the Bohr shell model, $e^2 = 1.440 \times 10^{-10} \text{ keV cm}$, $\mu_N^2 = 1.5922 \times 10^{-38} \text{ keV cm}^3$, L the orbital angular QUANTUM NUMBER for the transition, and $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of LIGHT.

Weisskopf single particle transition probability

[atomic] The theoretical PROBABILITY for the emission of a PHOTON resulting from a single PARTICLE degeneration based on the WEISSKOPF HALF-LIFE expressed as $P_{\text{prob}}(EL, ML)(W, u) = (\tau_{1/2}^\gamma(EL, ML)_{sp}) / (\tau_{1/2}^\gamma(EL, ML)_{\text{exp}})$.

Wentzel, Gregor (1898–1978)

[computational, general, quantum] Physicist and mathematician from Germany best known for his theoretical work on the QUANTUM THEORY of fields and fueled the development of QUANTUM MECHANICS. Together with the Dutch scientist HENDRIK KRAMERS (1894–1952) and the French physicist Léon Brillouin (1889–1969), they formulated the WKB solution (Wentzel–Kramers–Brillouin) model for solving the one-dimensional time-independent SCHRÖDINGER EQUATION in 1926 (see [Figure W.27](#)).



Figure W.27 Gregor Wentzel (1898–1978). (Courtesy of University of Leipzig, Leipzig, Germany.)

Wentzel–Kramers–Brillouin (WKB) solution method

[acoustics, computational, fluid dynamics, mechanics, quantum] Mathematical method for obtaining an approximate solution to the one-dimensional time-independent SCHRÖDINGER equation proposed by the German scientist GREGOR WENTZEL (1898–1978), the Dutch scientist HENDRIK ANTHONY KRAMERS (1894–1952), and the French physicist Léon Nicolas Brillouin (1889–1969) in 1926. This SOLUTION method specifically has QUANTUM MECHANICS applications, using a classical mechanics approach. The roots for this solution method date back to the French mathematician JOSEPH LIOUVILLE (1809–1882) from his work published in 1837.

Westinghouse, George (1846–1914)

[general] Engineer and entrepreneur from the United States known for his innovation and commercialization of electrical products and electrical support industry. George Westinghouse was an inventor and businessperson creating one of the largest electrical corporations at the early stages of electrical integration. George Westinghouse created the hydroelectric plant at Niagara Falls in 1896. One of George's inventions was the TRANSFORMER, allowing ELECTRICITY to be distributed and transmitted over long distances.

The Westinghouse Electric Corporation was created in 1886 and was a major player in the electric distribution network for the entire United States until it went defunct in 1999 (see [Figure W.28](#)).

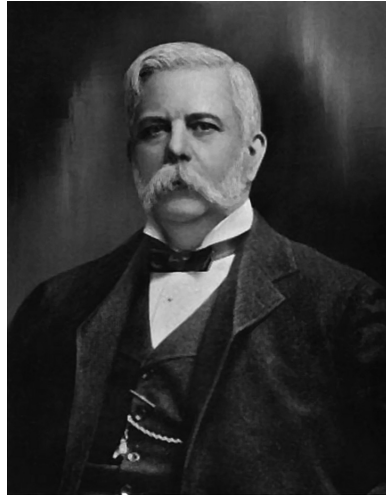


Figure W.28 George Westinghouse (1846–1914), photograph by Joseph G. Gessford. (Courtesy of U.S. Library of Congress Prints and Photographs Division)

Wet-bulb temperature

[thermodynamics] Temperature recording made with a THERMOMETER that has the “bulb” (liquid reservoir with mercury, ALCOHOL, or other expanding LIQUID) covered with a wick that is soaked in water, and the device is placed in a stream of MOIST AIR. The term comes from the field of PSYCHROMETRY (ENGINEERING dedicated to the thermodynamic properties of gas–vapor mixtures).

Wheatstone, Charles (1802–1875)

[energy, optics] Engineer and scientist from the Great Britain. Sir Charles Wheatstone is known for several inventions, one being the electric TELEGRAPH, and even though Wheatstone did not invent the MICROPHONE he did bring the term in CIRCULATION in 1827. In 1838, Sir Wheatstone designed a mechanism to view images in three dimensions by means of an optical structure, generating the 3D illusion. Additional work of

Charles Wheatstone was in the determination of unknown electronic components, introducing the WHEATSTONE BRIDGE (see [Figure W.29](#)).



Figure W.29 Charles Wheatstone (1802–1875).

Wheatstone bridge

[energy] Electric balancing circuit designed by CHARLES WHEATSTONE (1802–1875) in order to determine the value of an undetermined resistor by placing it in a PARALLEL CIRCUIT with power supply and adjust other known resistor values to form a circuit that has no current flowing. The RESISTOR value is derived from $R_1/R_2 = R_3/R_4$ (see [Figure W.30](#)).

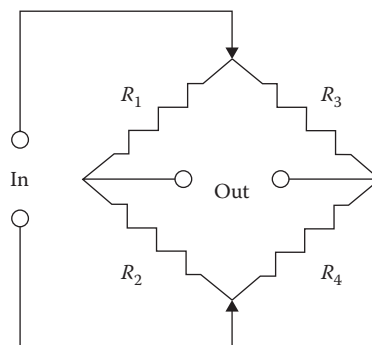


Figure W.30 Wheatstone bridge concept.

Wheeler, John Archibald (1911–2008)

[astrophysics/astronomy, atomic, computational, nuclear] Theoretical physicist from the United States. John Wheeler coined the term “BLACK HOLE” for phenomena in the UNIVERSE that seemed to have exceeding gravitational pull. Additional work by Wheeler was in the theoretical description of NUCLEAR FISSION in

collaboration with NIELS BOHR (1885–1962). One of Dr. Wheeler’s students was RICHARD FEYNMAN (1918–1988) (see [Figure W.31](#)).



Figure W.31 John Archibald Wheeler (1911–2008). (Courtesy of Princeton University, Princeton, NJ.)

White

[general, optics] Range of ELECTROMAGNETIC SPECTRUM covering the range blue through RED, perceived by the HUMAN EYE as white (see [Figure W.32](#)).



Figure W.32 White emission as the superposition of broad-band red, green, and blue light sources, in technicality covering the entire visible spectrum. Note that the combined paint of red, green, and blue dye will form a black appearance, whereas the lack of electromagnetic radiation absorbent dyes provides the reflected light of the superposition of all incident color wavelengths.

White dwarf

[astrophysics/astronomy, general] Medium size stars (with sizes less than eight times the size of our SUN) will degenerate into white dwarfs, processing through a stage of “RED GIANT” (for our Sun this object will have a diameter reaching the orbit of the planet EARTH) for approximately 1 billion years (in comparison to operating as a hydrogen FUSION STAR in the order of 10 billion years). Medium size stars are fusion engines producing helium from hydrogen in their cores. As the red giant collapses, the

helium will fuse into carbon and other heavier ELEMENTS. The first observation pertaining to a white dwarf was made by FRIEDRICH WILHELM BASEL (1784–1846) in 1844, with respect to his observations of Sirius, which was recognized as an unexplained anomaly. In 1863, Alvan Graham Clark (1804–1887) recognized this anomaly as a white dwarf. Large stars will degrade into NEUTRON stars or “black hole.” White dwarfs are extremely dense, approximately equivalent to the mass of our Sun compacted in the size of our Earth (see [Figure W.33](#)).

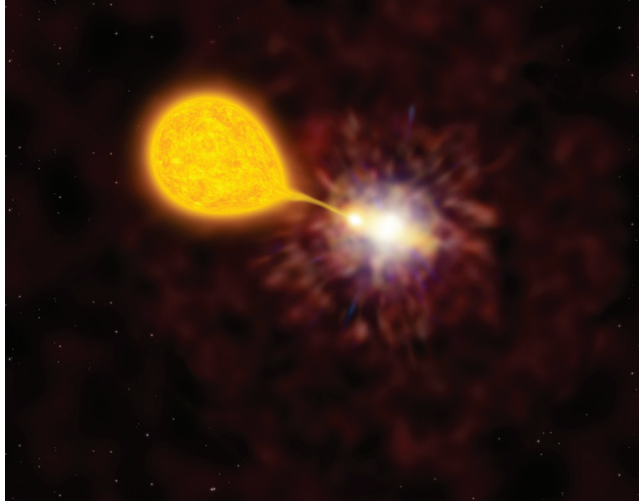


Figure W.33 Nova outburst with the White dwarf star in an orbit around a giant red star.

White light

[general] Temperature COLOR greater than 6000 K, broad range of emission wavelengths stretching from 340 nm or less through 650 nm or greater in the visible PERCEPTION. The SUN has an EMISSION SPECTRUM on the EARTH that equates to a black-body radiance of 5780 K, based on the Planckian radiator model (*also see* WIEN'S DISPLACEMENT LAW *and* CIE COLOR CHART).

White noise

[general] Indiscriminate and unsystematic arrangement of frequencies mixed in with the SIGNAL covering a broad wavelength range, with randomly fluctuating magnitudes as a function of frequency (see [Figure W.34](#)).

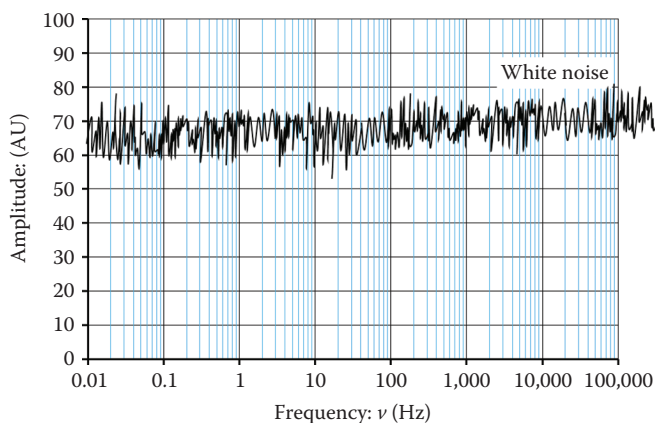


Figure W.34 Generalized frequency spectrum of White noise.

Wiedemann–Franz ratio

[atomic, nuclear, thermodynamics] See **LORENTZ NUMBER**.

Wien, Wilhelm Carl Werner Otto Fritz Franz (1864–1928)

[atomic, general, nuclear, thermodynamics] Scientist from the Prussian empire (Lithuania), known for his contributions to RADIATION spectra, specifically “black-body” radiation. Additional work of Wien contributed to a rudimentary model of the ATOM, based on the CATHODE ray interaction with atomic compounds, creating positive particles that are deflected by both electric and MAGNETIC fields. Since his work predates the QUANTUM THEORY, the close resemblance to quantum PHYSICS in his atomic model was remarkable. The empirical WIEN’S DISPLACEMENT LAW devised by Wilhelm Wien was adjusted by his colleague MAX PLANCK (1858–1947) to form the WIEN–PLANCK LAW, with a theoretical basis (see [Figure W.35](#)).



Figure W.35 Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928), along with the Swedish ophthalmologist Allvar Gullstrand (1862–1930).

Wien–Planck law

[atomic, nuclear, thermodynamics] RADIATION law theorized by MAX PLANCK (1858–1947), based on the work of his colleague WILHELM WIEN (1864–1928) in 1900. The Wien–Planck law, also referred to as the Planck radiation law provides a spectral distribution, accounting for the emission in the longer (low-energy) wavelengths expressed as $I_{\nu,T} = 2b\nu^3/c^2 \left\{ \exp(b\nu/k_bT) - 1 \right\}^{-1}$, which reduces to the WIEN’S DISPLACEMENT LAW when assuming $b\nu \gg k_bT$, where $I_{\nu,T}$ represents the energetic emission as a function of wavelength (with the associated frequency $\nu = c/\lambda$, with c the speed of LIGHT), at any specific wavelength, emitted per unit solid angle (Ω), as a function of

TEMPERATURE (T) per unit time (t) radiated over a normalized surface area (A), $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT, and the Boltzmann coefficient $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ (see Figure W.36).

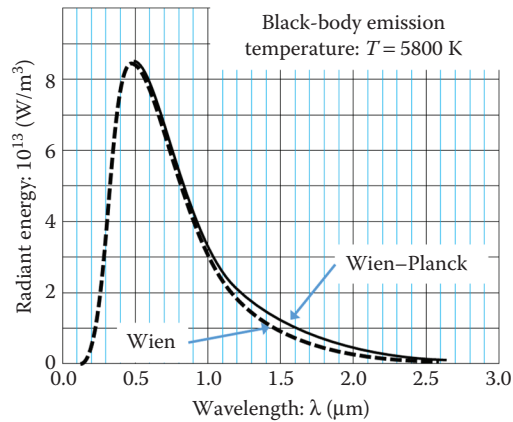


Figure W.36 Wien–Planck law.

Wien's displacement law

[atomic, nuclear, thermodynamics] RADIATION wavelength (emission peak in the distribution spectrum: λ_{peak}) versus temperature of the black-body (T) equivalence described by WILHELM WIEN (1864–1928) in 1893: $\lambda_{\text{peak}} T = \text{Const}$. In a greater detail, the energetic emission ($I_{\nu,T}$) spread out over a wavelength bandwidth, with a peak emission at λ_{peak} (with the associated frequency $\nu = c/\lambda$, with c the speed of light), per unit solid angle (Ω), as a function of temperature, per unit time (t) radiated over a normalized surface area (A) expressed as the spectral envelope function $I_{\nu,T} = (2b\nu^3/c^2)\exp(-b\nu/k_bT)$, with $b = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT and $k_b = 1.3806488 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$ the Boltzmann coefficient (see Figure W.37).

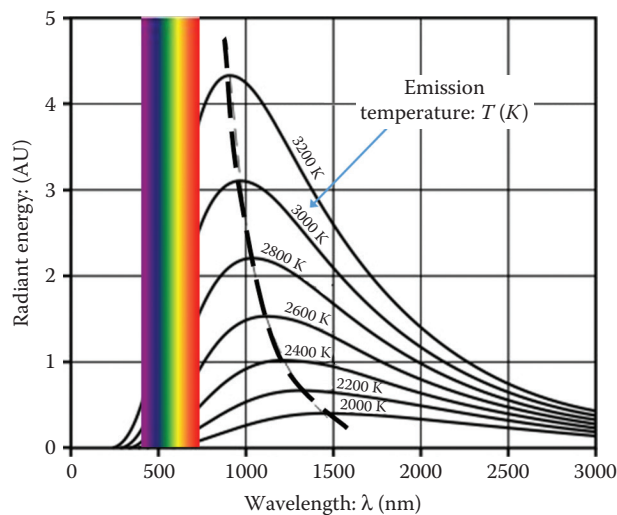


Figure W.37 Wien's displacement law.

Wigner, Eugene (Jenő Pál) (1902–1995)

[atomic, computational, nuclear, quantum] Physicist and mathematician from Hungary. Jenő Pál Wigner received the Nobel Prize in Physics for his work on ELEMENTARY PARTICLES and the theoretical description of the atomic NUCLEUS in 1963, shared with MARIA GOEPPERT-MAYER (GÖPPERT) (1906–1972) and JOHANNES HANS DANIEL JENSEN (1907–1973). Jenő Pál Wigner may be considered one of the founding fathers of QUANTUM chemistry (see [Figure W.38](#)).



Figure W.38 Eugene (Jenő Pál) Wigner (1902–1995). (Courtesy of Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN.)

Wigner distribution

[atomic, computational, nuclear] Momentum PROBABILITY distribution function expressed in 1932 by JENŐ PÁL (EUGENE) WIGNER (1902–1995), defining the WAVEFUNCTION ($\psi(q)$, as a function of location q ; the wavefunction can contain electric and MAGNETIC FIELD) and the representative state of the medium in QUANTUM MECHANICS. The general Wigner distribution for the state of a system is defined as $W(q, p) = (1/\pi\hbar) \int_{-\infty}^{\infty} \psi^*(q+y) \psi(q-y) e^{i2py/\hbar} dy$ semiclassical $(1/\pi\hbar) \int_{-\infty}^{\infty} q-y \hat{\rho} |q+y e^{i2py/b} dy$, where $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34} \text{ m}^2\text{kg/s}$ the PLANCK'S CONSTANT, ψ^* is the complex conjugate, p the momentum, y the position in free space, and $\hat{\rho}$ a density matrix that can be applied for a classical mechanical approach. The Wigner distribution can be used to analyze audio signals and the representative audio PERCEPTION as well as electrocardiograms next to quantum mechanical applications. In classical mechanical terms, the Wigner distributions hold information about the FREQUENCY SPECTRUM the group delay and the response function.

Wilkins, Maurice Hugh Frederick (1916–2004)

[biomedical, general, imaging] Physicist and molecular biologist from New Zealand. In 1953, Maurice Wilkins provided the imagery to support the experimental and theoretical work by JAMES WATSON (1928–) and FRANCIS HARRY COMPTON CRICK (1916–2004) on their efforts in DNA analysis and the discovery of the nature of the genetic structure of living organisms. Wilkins shared the Nobel Prize in Physiology/Medicine

with Watson and Crick in 1962 for their groundbreaking efforts supporting biological development and function and physiological formatting (see [Figure W.39](#)).

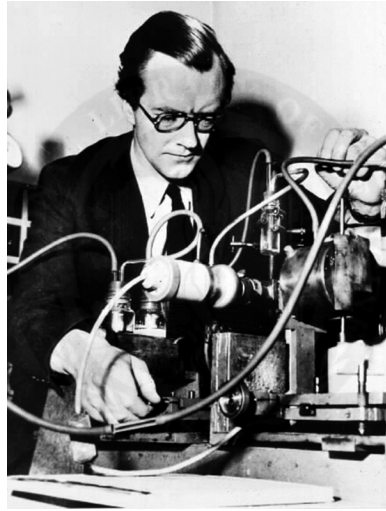
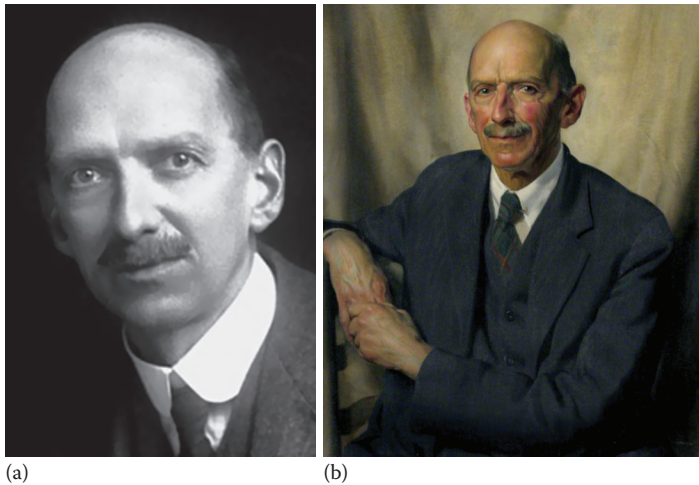


Figure W.39 Maurice Hugh Frederick Wilkins (1916–2004). (Courtesy of National Institutes of Health, Bethesda, MD.)

Wilson, Charles Thomson Rees (1869–1959)

[atomic, nuclear] Physicist from Scotland, Great Britain. Inventor of the cloud chamber used for tracking and identifying charged particles, for which he received the Nobel Prize in Physics in 1927, which he shared with ARTHUR HOLLY COMPTON (1892–1962) (see [Figure W.40](#)).



(a)

(b)

Figure W.40 (a) Charles Thomson Rees Wilson (1869–1959), in 1927. (Courtesy of Electric Scotland Muskegon, MI, USA.) (b) In 1936 painting by Herbert James Gunn. (Courtesy of Sidney Sussex College, University of Cambridge; Cambridge, UK.)

Wilson cloud chamber

[atomic, nuclear] Condensation chamber that produces a trail of droplets in suspension according to the trajectory of a charged PARTICLE or charge interaction. Generally an external electric and/or MAGNETIC FIELD is applied to influence the path of the respective particles and allow for QUANTIFICATION of charge and mass. The Wilson cloud chamber has been credited with the aid in the discovery of the positron, the verification of the COMPTON SCATTERING of electrons, experimentally illustrated PAIR FORMATION and pair annihilation, next to the transmutation of atomic nuclei. The Wilson cloud chamber was recognized by ERNEST RUTHERFORD (1871–1937) as one of the most influential discoveries of the day. Also known as cloud chamber (see [Figure W.41](#)).

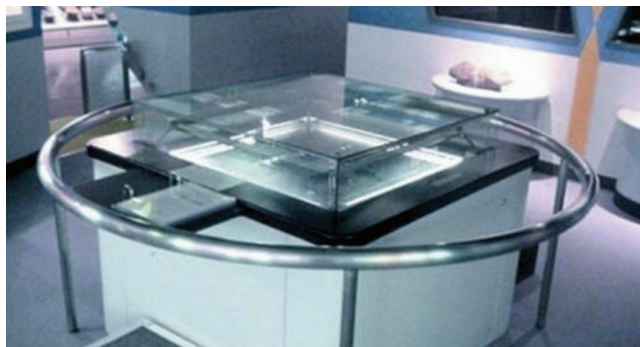


Figure W.41 Wilson cloud chamber. (Courtesy of Electric Scotland, Muskegon, MI, USA.)

Wimshurst, James (1832–1903)

[electronics, general] Engineer and scientist from Great Britain. Inventor of the WIMSHURST MACHINE, creating sparks through electrostatic charge build-up from rotating disks that have opposite revolution rubbing against copper brushes to conduct the charges off to either Leyden Jars or electrodes. James Wimshurst followed the example set out by the French scientist Ferdinand Philippe Edouard Carré (1824–1900), who also invented and designed refrigeration equipment, the German physicist Wilhelm Holtz (1836–1913), with his MACHINES exhibited in 1865 and 1867, as well as another German physicist, AUGUST JOSEPH IGNAZ TOEPLER (1836–1912) with his machine on display in 1865. Other inventors working on the same principle were by the German scientists ROGER VOSS (early eighteen hundreds) and J. ROBERT VOSS (early eighteen hundreds). James Wimshurst also invented a VACUUM machine. Other contributions by Wimshurst were in his field of nautical construction, devices to indicate the stability

of large ships and designed the manner in which a lighthouse in open sea could be powered by ELECTRICITY (see [Figure W.42](#)).



Figure W.42 James Wimshurst (1832–1903).

Wimshurst machine

[electronics, general] Electrostatic device made with two insulating disks that rotate in opposite directions and form nonfriction based electrostatic charge build-up (no contact to generate charge build-up except for the current wires). The machine was designed and constructed by JAMES WIMSHURST (1832–1903) in 1878. The insulating disks have small sections of conducting material at fixed intervals that are brought in contact with copper brushes when rotating. The electrostatic charge generated from the two disks is transferred to either electrodes which produce an arc, or to Leyden Jars for “storage.” The first primitive form of an electrostatic frictional machine was invented and fabricated by OTTO VON GUERICKE (1602–1682) in 1663. Various versions were created over the years, with a 1.6 m diameter set of GLASS disks in 1783 by the Dutch physicist and inventor Martin van Marum (1750–1837). The Van Marum disks had the capability to produce

electrical charge of either polarity, using FRICTION (*also see* VAN DE GRAAFF GENERATOR *and* TESLA COIL) (see [Figure W.43](#)).



Figure W.43 Wimshurst machine. (Courtesy Lateral Science Co., UK.)

Wing

[astrophysics, fluid dynamics, mechanics] Structure that provides a LIFT during a flight. Bird wings have a special construction where the feathers create the optimal conditions to support a lift and elevation as well as sustain a flight while allowing for minimal INTERFERENCE on the upward force during the up–down movement of the wings during ascension. Mammals with wings, such as bats, squirrels, and monkeys have no feathers and rely on the turning of the solid wing (e.g., SKIN, membrane) while undergoing upward MOTION to still take advantage of the Bernoulli principle, and not push the animal down. Insect wings are generally also constructed from a membrane; however, some wings can be very intricate, such as the butterfly and moth wing. For a fixed-wing aeroplane (airplane), the Bernoulli principle is applied to provide a lift as a result of the forward velocity, creating a pressure gradient that provides a lift that supports the airplane and its LOAD (*also see* LIFT) (see [Figure W.44](#)).



Figure W.44 Wing design.

Wollaston prism

[general, optics] Polarizing prism, and beam splitter. The Wollaston prism separates the ordinary and the extraordinary rays, both polarized in respective orthogonal directions. The extraordinary ray is polarized parallel to the long-axis planes of all windows, specifically of the separation plane. The DIVERGENCE between the ordinary and the extraordinary ray is a function of the ANGLE of the PRISM windows. The Wollaston prism finds applications in CD and DVD players in combination with a quarter-WAVE plate (see [Figure W.45](#)).

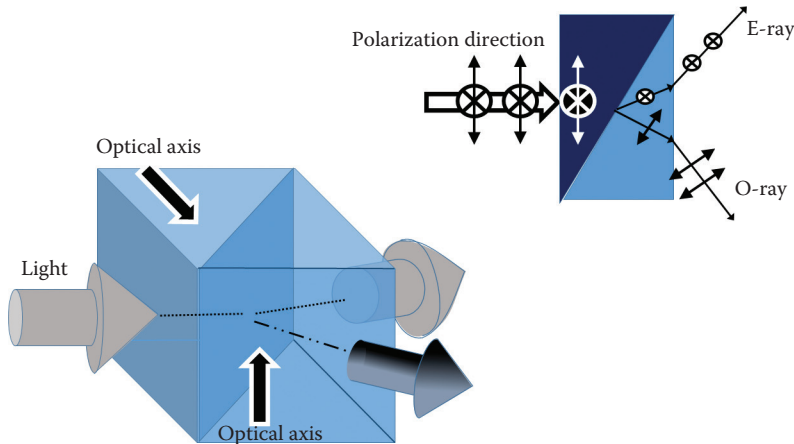


Figure W.45 Wollaston prism.

Womersley, John Ronald (1907–1958)

[biomedical, fluid dynamics] Physiologist and mathematician from Great Britain, known for his interpretation of viscous flow. Some of Womersley's major contributions have been to the fields of textiles and biomedical FLUID DYNAMICS. The work of Womersley expanded on the PULSATILE FLOW model developed by the German physiologist Otto Frank (1865–1944) based on the Windkessel phenomenon in 1899, integrating the Navier–Stokes equations (see [Figure W.46](#)).

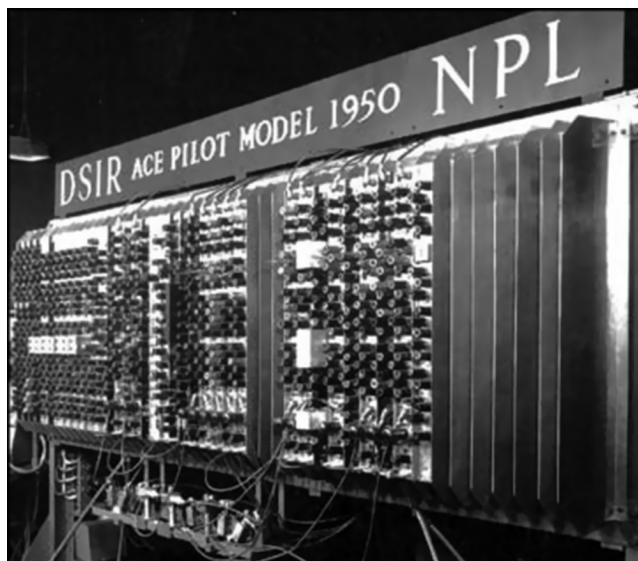


Figure W.46 Computer conceived and produced by John Ronald Womersley (1907–1958).

Womersley number, ($\alpha_{wo} = r\sqrt{\rho\omega/\eta}$)

[biomedical, fluid dynamics] Dimensionless number used to scale the dominant features in a PULSATILE FLOW. The Womersley number is defined as the ratio of changing inertial forces resulting from the localized acceleration in each period of the pulsatile MOTION with respect to the viscous forces, where r is the radius of the conduit (BLOOD vessel, PIPE, etc.), ω is the ANGULAR VELOCITY due to changes in pressure gradient of the fluid in motion that is directly related to the FREQUENCY (ν) of the OSCILLATION ($\omega = 2\pi\nu$), ρ the fluid density, and η the VISCOSITY. In this approximation the elastic behavior of the WALL is considered to be negligible.

Wooster, William Alfred (Peter) (1903–1984)

[general] Scientist and mineralogist from the United States. The work of Wooster contributed to the material science aspects of crystallography.

Work (W)

[general, mechanics, nuclear] ENERGY resulting from a constant force F applied at an ANGLE θ with the MOTION performed over a DISTANCE s defined as $W = \vec{F} \cdot \vec{s} = Fd \cos \theta$, or in integral form: $W = \int \vec{F} \cdot d\vec{r} = \int F \cos \theta dr$. For rotation, this becomes: $W = \tau \Delta \theta$, where τ is the applied torque, and θ the angle of revolution. In case the force applied varies over time or over sections (s_i), the work can be summarized as calculated in stages in which the force can be considered as a constant: $W = \lim_{\Delta s_i' \rightarrow 0} \sum_i \vec{F}_i \cdot \vec{s}_i'$. (Note: work done by SPRING or by GRAVITY is a classic example of a nonlinear force.) With respect to energy, the following can also be said: work done on an object is equal to the change in KINETIC ENERGY (KE) of this object: $W = KE_2 - KE_1$. Work that is independent of the path followed between the beginning and the end point is defined as the result of a conservative force. The work done can be mechanical ($W_M = P\Delta V + v\Delta P$, where P is the pressure of a system, and V the partial volume occupied by the changing medium); or the work can be electrical ($W_e = -nF_{\text{Far}}\Delta V_{\text{elec}}$, where n is the number of transferred charges, $F_{\text{Far}} = 96,485 \text{ C/mol}$ the FARADAY CONSTANT, and ΔV_{elec} the maximum difference in electrical potential achieved through the motion of the charges) (see Figure W.47).

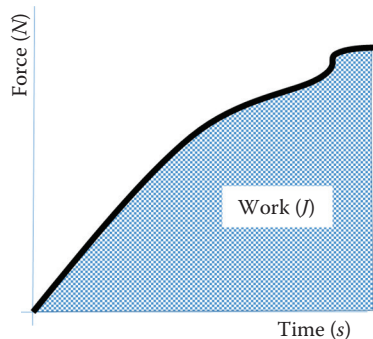


Figure W.47 Graph representing work as the area under the curve of force against the time the force is applied.

Work function (ϕ_{elec} in electron volt: eV)

[atomic, biomedical, electronics, general, nuclear] ENERGY needed for an ELECTRON to free itself from a surface, such as in an ELECTRON TUBE, or a PHOTO CELL used in the detection of LIGHT or to generate ELECTRICITY (also see PHOTO-VOLTAIC and PHOTOELECTRIC EFFECT). The work function for sodium is $\phi_{\text{elec}}|_{\text{Na}} = 2.28 \text{ eV}$, for copper: $\phi_{\text{elec}}|_{\text{Cu}} = 4.70 \text{ eV}$, whereas the work function for platinum is $\phi_{\text{elec}}|_{\text{Pt}} = 6.35 \text{ eV}$.

Work–energy theorem

[general, mechanics] The work (W) performed by a system equals the change in KINETIC ENERGY (KE) of that system: $W = \Delta KE$. This principle indicates the general interest in change, not so much to total energy content of a system, which technically includes all atomic and molecular energy.

Worthington jet

[fluid dynamics] Cavitation flow resulting from the impact of a solid sphere with a free (LIQUID) surface. The height of the JET (H_j) is a function of the object size (sphere diameter: D_b), velocity of impact, and the medium the object is impacting with, specifically there is a difference between Newtonian and non-Newtonian liquids. For an infinitely wide and infinitely deep pool of liquid, infinite being a relative term, at least three times the dimensions of the drop height may be a good approximation to avoid boundary effects. Note that the Worthington jet can also be generated by an object dropping in a pool of sand or other granular media. The viscosity of the liquid medium will dramatically impact the final outcome as well. With all factors considered, the height of the jet is defined by the following conditions: $H_j/D_b = f(\rho_r^*, Re, Fr)$, where $\rho_r^* = \rho_b/\rho_m$ the RELATIVE DENSITY from the ball (b), to the medium (m), $Re = \rho_m v D_b / \eta_e$ the REYNOLDS NUMBER, with η_e the effective viscosity of the medium, v the impact velocity, and subsequently $Fr = v / \sqrt{g D_b}$ the Froude number, with g the GRAVITATIONAL ACCELERATION. The mechanism of a liquid droplet falling on a solid surface also generates a Worthington jet; however, the conditions are different from breaking a liquid surface. The recoil force in the latter case is provided by the SURFACE TENSION of the liquid (F_τ), and is a function of the Weber number. The Weber number for a spherical fluid is $We = \rho v^2 D_b / F_\tau$. For a small Weber number, the surface tension will dominate and create a noticeable rebound and Worthington jet formation, whereas for a large Weber number, the kinetic ENERGY will dominate, resulting in a break-up and dispersal. No conclusive definition of the height of the rebound of the drop can be provided due to the wide range of boundary conditions, and only the influences can be described. The complete analysis of the Worthington jet falls under computational FLUID DYNAMICS (see [Figure W.48](#)).



(a)



(b)

Figure W.48 (a,b) Worthington jet.

W-Particle

[nuclear] Product of the DECAY process for a NEUTRON, delivering a W-particle and a PROTON; the “W” represents “weak,” for WEAK INTERACTION under the GAUGE THEORY. The W-particle is a VECTOR BOSON. All vector bosons are W^+ , W^- , and Z^0 . The mass for the W-vector bosons is $81 \text{ GeV}/c^2$, with $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of LIGHT. W-particles are highly unstable (decay time $\tau_d = 10^{-24} \text{ s}$) and decay into an electron–electron-antineutrino pair. The W-particle was introduced in 1956 by the theoretical physicist from the United States Julian Seymour Schwinger (1918–1994). Based on theoretical assumptions, the W-particle should be massless; however, due to the presence of the Higgs field, they acquire an ad-hoc spinless, SCALAR field, which provides the ENERGY to yield the REST MASS. In the theoretical description, the spin-0 Higgs bosons condense into a GROUND STATE that applies the classical field to the W-particles as well as the Z-particles, limiting their mobility to below light-speed interactions (see [Figure W.49](#)).



Figure W.49 W-boson (artist impression).

Wu, Chien-Shiung (Wú Jiànxíóng; 吳健雄) (1912–1997)

[atomic, nuclear] Scientist from mainland China. Dr. Wu was a collaborator on the MANHATTAN PROJECT. On an experimental approach, Chien-Shiung Wu illustrated that conservation of PARITY does not apply under NUCLEAR FISSION and NUCLEAR FUSION. Other efforts by Wu were in RADIOACTIVITY and the beta DECAY of isotopes under gaseous DIFFUSION (see [Figure W.50](#)).

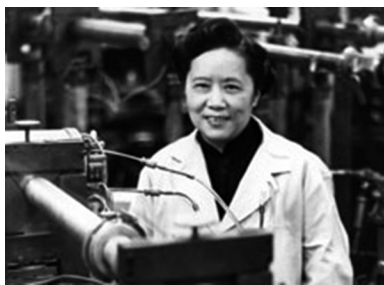


Figure W.50 Chien-Shiung Wu (Wú Jiànxíóng; 吳健雄) (1912–1997), credit #2205. Wu, ChienShiungInLab. (Courtesy of University Archives, Columbia University in the City of New York, Photographer Manny Warman.)



X-ray

[biomedical, nuclear] Electromagnetic “Röntgen” RADIATION with wavelength between 0.01 and 10 nm. Quite frequently the term Röntgen radiation is found to describe this type of radiation to credit the German discoverer Wilhelm CONRAD RÖNTGEN (1845–1923), published in 1895. X-ray radiation is generated as a result of electron transitions (note that GAMMA RAY can be very similar, but its origin lies in the atomic NUCLEUS). X-ray radiation is a by-product of NUCLEAR FUSION or FISSION (ISOTOPE decay) and can be artificially generated by bombarding for instance a tungsten, rhenium, or molybdenum-alloy disk with fast electrons. The ANODE rotates to prevent localized overheating (cooling is a major requirement for the filament). The X-ray exposure during a medical exam results from exposure of a rotating anode in a Coolidge type tube with electrons from a fixed location CATHODE. The exposure to X-ray radiation falls under dosimetry and has strict limits to ensure prevention of biological damage. X-ray radiation exposure is quantified by gray ([Gy]) or rad ([rad]) as units of cumulative exposure, or as equivalent dose with respect to the potential of generating IONIZATION, obtained by multiplication of the ABSORBED DOSE by a factor describing the type and ENERGY of the radiation in Sievert ([Sv], old unit [rem]). The gray is a unit for absorbed dose in joule per kilogram, named in honor of the British originator of radiation control and his attempts to limit biological (i.e., genetic) and burn damage, Louis Harold Gray (1905–1965); proposed in 1940, defined in 1975. Exposure in excess of 100 Gy will result in an eventual, but unavoidable, death. Locally applied dosage in the order of 50 Gy is standard in RADIATION THERAPY, whereas a computed TOMOGRAPHY scan requires exposure in the order of 5 mGy and flying at 30,000 ft (~10 km) altitude is not significantly higher than the solar X-ray exposure obtained down on the EARTH during a picnic. The rad has primarily a historic value, defined in 1953 and $1 \text{ rad} = 0.01 \text{ Gy}$; sometimes used as a equivalent to the sporadic and mainly colloquial röntgen unit. The radiation weight factor (W_R) is as follows to obtain the equivalent dose: X-ray, gamma, beta, and muons $W_R = 1$; protons $W_R = 2 - 5$; NEUTRON radiation $W_R = 5 - 20$ depending on the energy; and for ALPHA PARTICLES and heavy nuclei, PARTICULARLY those produced under NUCLEAR FISSION, $W_R = 20$. The discovery of X-ray fueled the research into RADIOACTIVITY and FLUORESCENCE. Additionally, X-ray is used for a three-dimensional inspection on a diffraction level for atomic structure and for attenuation based on the density applied to nondestructive testing, airport human body scanners, and medical inspection as well as treatment options. Computed tomography (CT- or CAT SCAN) uses X-ray radiation from a multitude of directions arranged in a circumferential array or by a moving source with fixed scintillation counters or

photomultiplier tubes as the detection mechanism. The CT scan applies the line-of-flight principle to reconstruct a three-dimensional IMAGE from intersect points at the lines of attenuation in transmittance (see Figure X.1).

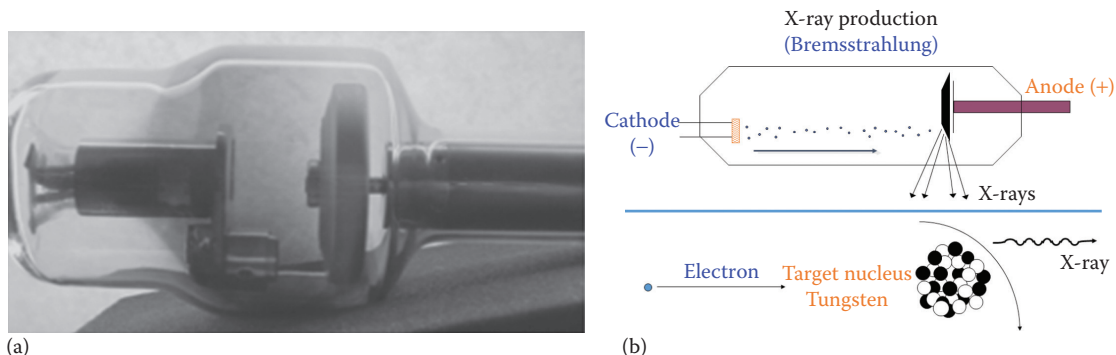


Figure X.1 (a) X-ray generation and (b) X-ray spectrum.

X-ray, characteristic

[atomic, nuclear] The RADIATION emitted resulting from ENERGY transitions in the inner bands of the BOHR ATOMIC MODEL, associated with a high-energy level electron BINDING ENERGY. Generally the narrow line-width characteristic radiation is superimposed on the broad-band BREMSSTRAHLUNG spectrum (BREMSSTRAHLUNG). For the VALENCE electrons, the EMISSION SPECTRUM is defined by the ENERGY transitions in the outer bands. The electron orbits are defined in the Bohr atomic model, described by NIELS HENRIK DAVID BOHR (1885–1962). The change in ENERGY LEVEL in the outer bands of the atomic model generates photons with frequency ν expressed by $h\nu = E_i - E_f$, where $h = 4.1356692 \times 10^{-15}$ J s is the Planck constant. In the inner electron bands, the energy levels are much greater and so are the energy QUANTA involved in the transitions. The wavelength (λ) of the emitted PHOTON is now proportional to the ATOMIC NUMBER (Z) of the material and the difference in the electron orbit from the inner orbit outward, with the inner orbit indicated by the condition $n = 1$, where n identifies the lower orbit with the highest energy and is defined as $1/\lambda = R_{\text{Ry}} (Z - 1)^2 \left[(1/(n^2)) - (1/(n + m)^2) \right]$, with $n \geq 1$ and $m \geq 0$ and $R_{\text{Ry}} = 1.097373 \times 10^7 \text{ m}^{-1}$ the RYDBERG CONSTANT. The associated frequency is $\nu = c/\lambda$, with c the speed of LIGHT. Hence there are grouping of emission lines that result from electron transitions ending at the same orbital level but starting from one or more levels of separation. The emission lines were classified by CHARLES GLOVER BARKLA (1877–1944) in 1911 as K -lines, L -lines, M -lines, and N -lines, respectively: $K_\alpha, K_\beta, K_\gamma, K_\delta, L_\alpha, L_\beta, L_\gamma, L_\delta, M_\alpha, M_\beta, M_\gamma, M_\delta, N_\alpha, N_\beta, N_\gamma, N_\delta$, with each successive alphabetical indicator (capitalized Roman letter) indicating the lower level (K for $n = 1$), with alphabetical subscript (Greek) indicating an increment in the value m , or a larger QUANTUM JUMP. This holds due to the fact that the lower level (e.g., $n = 1$) has under normal equilibrium conditions two electrons, but will have one electron missing because of excitation. Concurrently the net NUCLEAR CHARGE will be reduced resulting in the equivalent COULOMB FORCE proportional to $+e(Z - 1)$ (according to GAUSS'S LAW), not $+e \cdot (Z)$ (see CHARACTERISTIC X-RAY) (see Figure X.2).

Molybdenum (Mo) target impacted by electrons accelerated from a potential difference of 35 kV potential

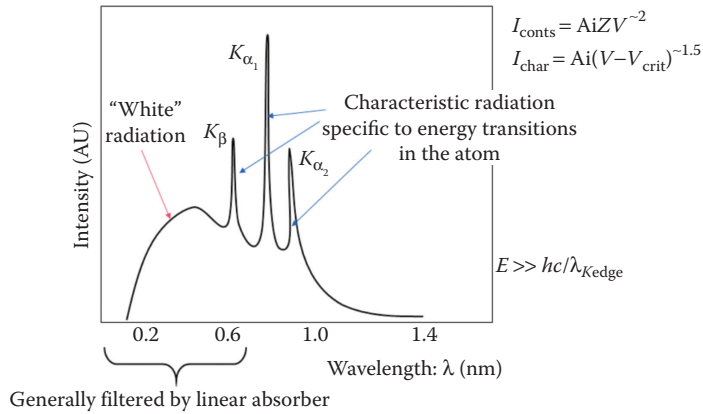


Figure X.2 Characteristic X-ray radiation.

X-rays diffraction in crystals

[atomic] The use of X-RAY radiation for crystal LATTICE analysis, crystallography (see the VON LAUE METHOD) (see Figure X.3).

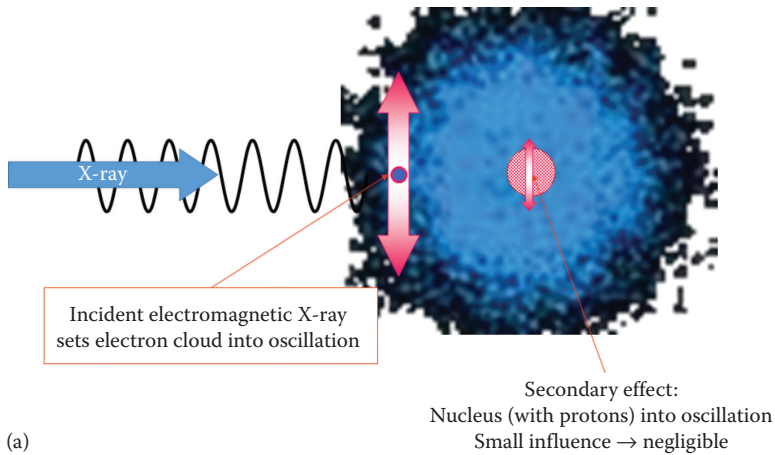


Figure X.3 (a–c) X-ray diffraction.

(Continued)

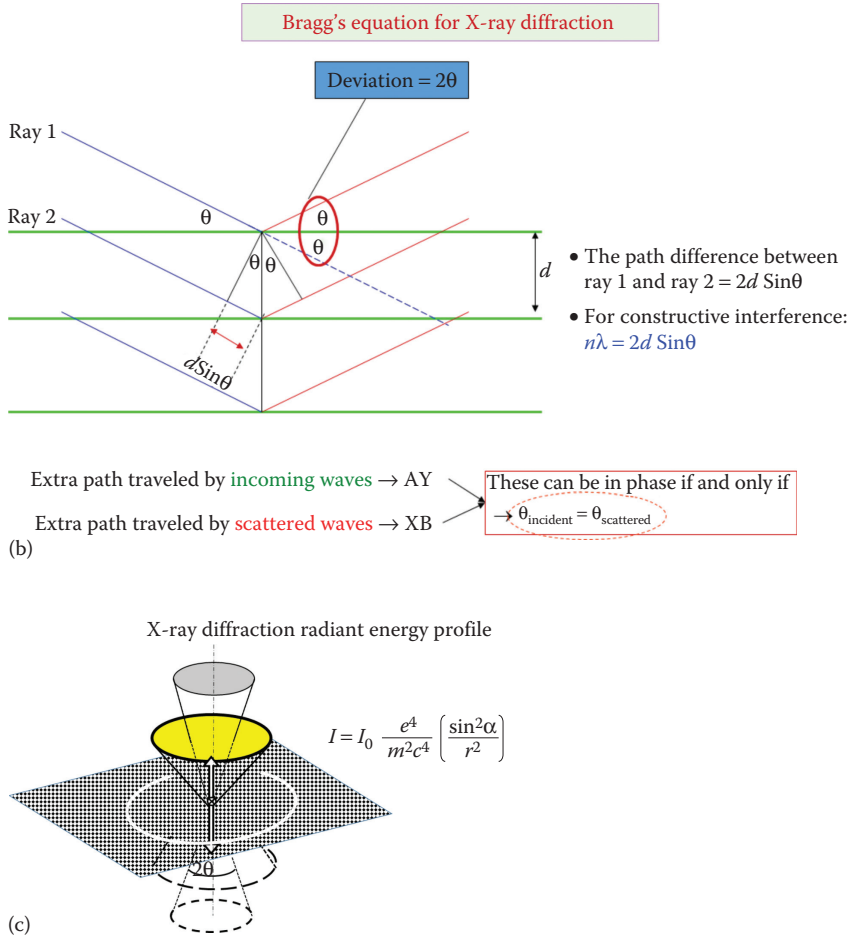


Figure X.3 (Continued) (a–c) X-ray diffraction.

XY model

[computational, thermodynamics] Special case for the situation $n = 2$ with regard to the n -vector lattice model pertaining to classical MECHANICS in a multidimensional setting. The D -dimensional lattice model (Λ) is defined by sites (i) , each occupied by a SPIN or rotator vector (spin configuration) $\vec{s} = (\vec{s}_i)_{i \in \Lambda}$, $\vec{s}_i = (\cos \theta_i, \sin \theta_i)$, which have orthogonal $O(2)$ symmetry (rotation around a fixed point) and $U(1)$ symmetry (GAUGE SYMMETRY, pertaining to the electromagnetic force). The XY model describes the PROBABILITY distribution for magnetization configuration of a medium that can be magnetized, for instance SUPERFLUID helium and certain LIQUID crystals, generally possessing a certain symmetry. The XY model contains the conditions for PHASE transitions within the system. In statistical mechanics, the probability $(P(\mathbb{S}))$ that a system possesses a certain state $(\mathbb{S})$ while at a certain TEMPERATURE (T) with ENERGY $E = \sum_{(i,j)} \vec{s}_i \cdot \vec{s}_j$ is described as $P(\mathbb{S}) = e^{-[E(\mathbb{S})/k_b T]} / Z_\ell(1/k_b T)$, where $k_b = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg/s}^2 \text{ K}$ the Boltzmann coefficient, and $Z_\ell(1/k_b T) = \sum_{\mathbb{S}} e^{-[E(\mathbb{S})/k_b T]}$ the linearized portion of the PARTITION FUNCTION that is tied to the free energy $G_\ell(1/k_b T) = (1/\ell^D) \ln Z_\ell(1/k_b T)$, with D the dimension of the system (i.e., the DEGREES OF FREEDOM). Also known as the classical rotor model or the classical rotator model.

Yang, Chen Ning (清华大学) (1922–)

[computational] Physicist from China. Chen Ning Yang received the Nobel Prize in Physics in 1957 for his work on the PARITY OF ELEMENTARY PARTICLES, which he shared with Tsung-Dao Lee (李政道: 1926–) (see [Figure Y.1](#)).



Figure Y.1 Chen Ning Yang (清华大学) (1922–).

Yang–Mills field

[computational] The field that rules the Yang–Mills theoretical approximation. This QUANTUM field is based on PERTURBATION THEORY (developed in a series with units p), which can be solved only once the perturbation function ($\beta(\alpha_s)$; $\alpha_s = g_s^2/4\pi$ the coupling of the vector potential with g_s the gauge coupling constant that is indicative of the strength of the interaction) is known. The ENERGY field is a running coupling-based approach: $\mu_p^2(d\alpha_s/d\mu_p^2) = \beta(\alpha_s)$, μ_p the perturbation series components ($\mu_{p=0}$ providing the exact SOLUTION for the initial conditions). In this the perturbation at short wavelengths can be written as $\beta(\alpha_s) = -(11N/12\pi)\alpha_s^2 + (17N^2/24\pi^2)\alpha_s^3 + R(\alpha_s^4)$, where $R(\alpha_s^4)$ is a rest term (error term) and N represents the GAUGE SYMMETRY group rank, defining the number of gauge fields (e.g., photons,

weak bosons, strong bosons, and gluons); however, the long wavelength limit is not well defined (INFRARED limit) (see Figure Y.2).

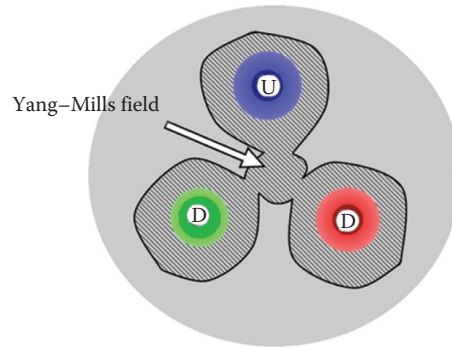


Figure Y.2 Yang–Mills field. “U”—Up quark; “D”—Down quark.

Yang–Mills theory

[computational] Theoretical description of the elementary forces (the GAUGE THEORY) between protons and neutrons introduced by CHEN NING YANG (1922–) and Robert Laurence Mills (1927–1999), published in 1954. The Yang–Mills theory is a typical example of the gauge theory applied to the interaction of a weak current from a LEPTON interacting with a charged strong VECTOR BOSON.

Yield length

[general, mechanics] Stretch length applied before failure occurs (see Figure Y.3).

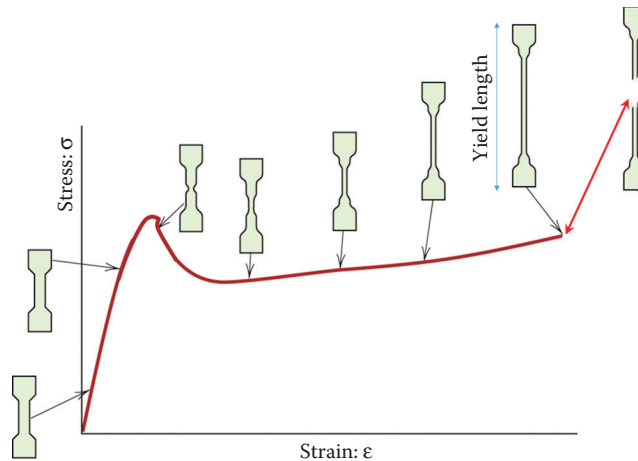


Figure Y.3 Yield length.

Yield stress (τ^*)

[fluid dynamics, mechanics] The applied stress threshold to transform a pseudoplastic or dilatant system into a homogeneous flow. $\tau^* = K_y(\epsilon - \epsilon_{\min})^2$, where K_y is a constant that depends on the colloid solution PARTICLE size and shape (e.g., sphere, rod, ellipsoid, and the respective aspect ratio of the sizes), $[\epsilon]$ the

concentration of constituent “ ϵ ,” with threshold minimum concentration $[\epsilon_{\min}]$. This applies to a tube flow, but also to stirrer interaction (see Figure Y.4).

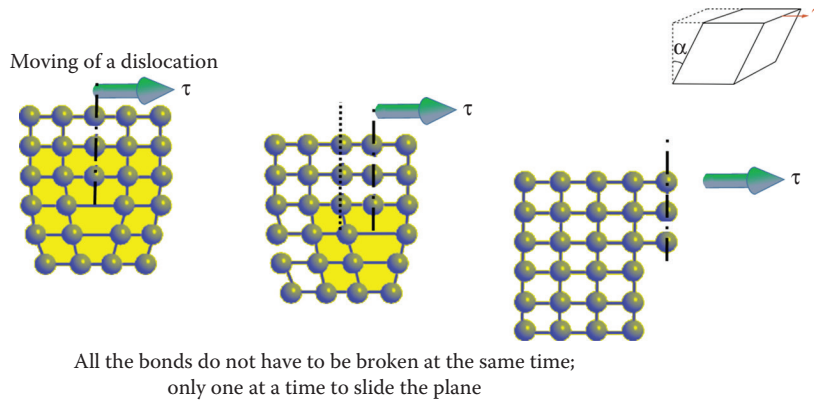


Figure Y.4 Yield stress.

Young, Thomas (1773–1829)

[mechanics, optics] English physician and physicist. Young provided experimental proof in 1801 that electromagnetic RADIATION has a WAVE characteristic next to the PARTICLE identity shown with Snell’s experiments and theoretical description of REFLECTION and refraction. The wave characteristics were elucidated from the double slit INTERFERENCE pattern with a single source, resembling the node, crest, and trough pattern produced by water waves (see Figure Y.5).



Figure Y.5 Thomas Young (1773–1829). (Courtesy of The Royal Institution, UK, originally painted by Thomas Lawrence; copied either by Hugh Goldwin Riviere or Mabel Beatrice Messer.)

Young–Laplace equation

[biomedical, chemical, fluid dynamics, mechanics, thermodynamics] Nonlinear partial differential equation that is used to define the CAPILLARY pressure gradient across an equilibrium interface between two immiscible fluids, both stationary. The name is based on the experimental work of the English scientist THOMAS YOUNG (1773–1829) in 1805, describing SURFACE TENSION with the assistance of the French mathematician PIERRE-SIMON DE LAPLACE (1749–1827) in the mathematical formulation in 1806. The force balance between the pressure (P) and the surface tension (F_τ) at the surface S with circumference C is defined as $\int_S (P_1 - P_2) \vec{n} dS = -F_\tau \oint_C \vec{t} \times \vec{n} d\vec{r}$, where $\vec{t}$ is the tangent at the curve of the enclosure of the surface and $\vec{n}$ the normal to the surface, pointing in the direction from fluid 1 to fluid 2. Viscous forces are not applicable since the situation is stationary. This reduces to $(P_1 - P_2) = \Delta P = F_\tau \nabla \cdot \vec{n}$, where $\nabla = \sum_i \partial / \partial x_i$ is the Laplace operator, yielding $\nabla \cdot \vec{n} = 0$ for a flat interface.

Young's modulus (Y_n)

[general, mechanics] Plotting STRESS (σ_n) versus STRAIN (ϵ_n) provides a graph of the ELASTICITY of a solid; the linear section of the curve can be represented by a line function with a slope, where n indicates the DEGREES OF FREEDOM (primarily: x, y, z , respectively 1, 2, 3). Also called elastic modulus or bulk modulus under specific boundary conditions. The Young's modulus is hence defined as the stress in longitudinal direction per unit strain where the transverse modes are not confined (i.e., ϵ_2 and ϵ_3 are allowed to change). The slope of the linear part of the stress–strain curve is defined as the Young's modulus (Y_n) of that material under stress: $\sigma_n = Y_n \epsilon_n$, as defined by HOOKE'S LAW of linear elasticity. Technically the value of the Young's modulus can be different for a material under tension or under compression, in which case both values will be listed in reference books such as the *CRC Handbook of Chemistry and Physics*. The Young's modulus is the linear counterpart of the BULK MODULUS. Multidimensionally (specifically cubically), the Young's modulus can be expressed by the elasticity:

$$\sigma_m = C_{mn} \begin{bmatrix} \epsilon_{00} & \cdots & \\ \vdots & \ddots & \vdots \\ & \cdots & \epsilon_{nn} \end{bmatrix},$$

using $C_{mn} = \partial \sigma_m / \partial \epsilon_n$, as $Y_{\text{cub}} = [(C_{11} - C_{12})(C_{11} + 2C_{12})] / [(C_{11} + C_{12})]$. (see Figure Y.6)

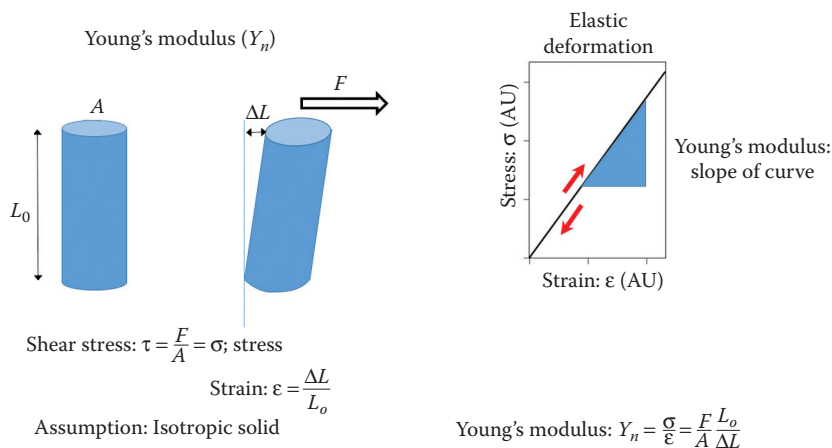


Figure Y.6 Young's modulus.

Young's slit experiment

[optics] In order to produce two apparently coherent sources (not truly coherent, but good enough for the day) THOMAS YOUNG (1773–1829) placed a LIGHT SOURCE behind a single slit, which in turn produced an expanding WAVEFRONT that illuminated two closely separated slits. The two slits in turn produced two relatively coherent sources that resulted in an INTERFERENCE pattern on a screen placed behind the two slits. This interference pattern produced in 1801 reaffirmed the original hypothesis that light is a WAVE. The Newtonian particle concept for light still prevailed until well into the twentieth century. The interference pattern resembles the pattern generated from waves in water with two “coherent” sources, generated in a similar fashion. The DISTANCE of the locations of maximum interference with respect to the central maximum is given in terms of wavelength, where a whole wavelength difference in path length produces a positive interference and half a wavelength extinguishes the light locally. The angular (θ) dependence for the maxima is given as $a \sin \theta_m = m\lambda$, where $m = 0, 1, 2, \dots$ indicates the order of the maximum and a is the separation distance between the two slits. The original experiment used WHITE LIGHT, which resulted in a more pronounced separation of colors at greater distance from the center, with a white central interference line. Using a laser will produce a well-defined intensity (brightness) pattern (see [Figure Y.7](#)).

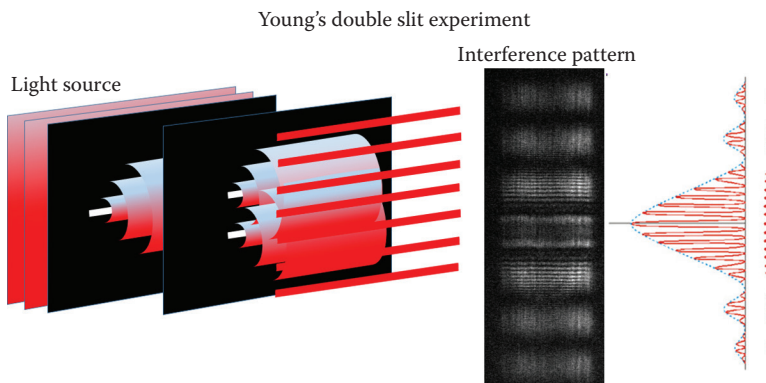


Figure Y.7 Young's slit experiment.

Yrast line

[nuclear] In the nuclear structure there is interaction between ENERGY levels, including the Coriolis coupling between energy bands (remember the Schrödinger WAVE equations [QUANTUM MECHANICAL PROBABILITY] and the fact that every moving object has a wave associated; de Broglie). The yrast line connects the yrast states of the lowest energy in the nuclear structure for a given angular momentum (see Figure Y.8).

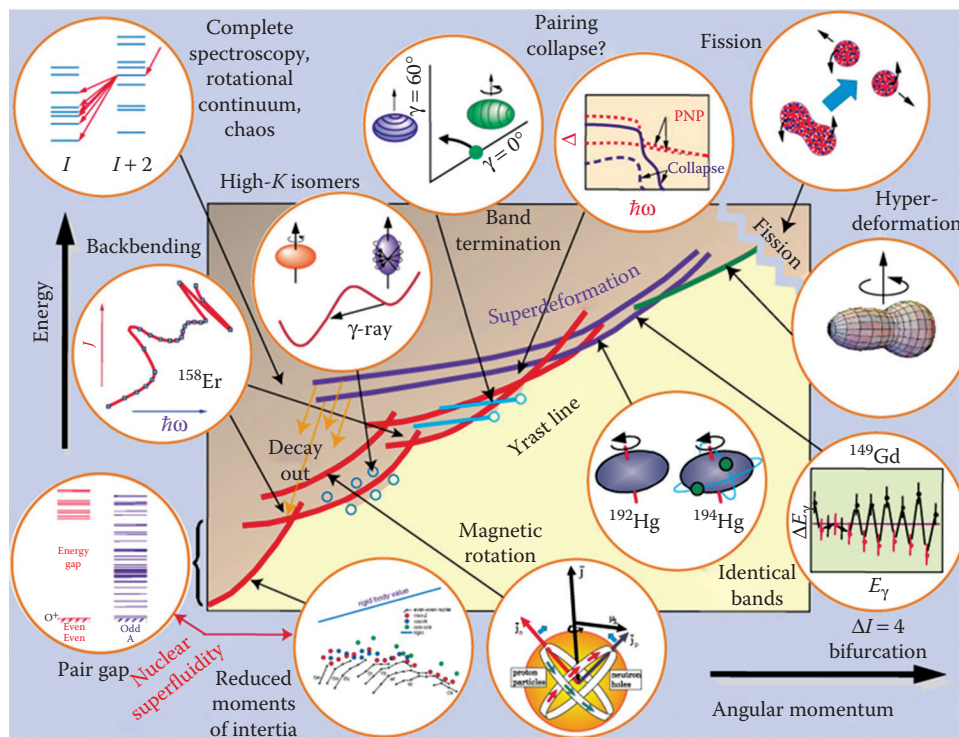


Figure Y.8 Yrast line. (Courtesy of Mark A. Riley, John D. Fox Accelerator lab, Florida State University, Tallahassee, FL and Witold Nazarewicz, Michigan State University, East Lansing, MI.)

Yrast region

[nuclear] In the nuclear structure, the ENERGY band just above the YRAST LINE is the yrast region. The yrast region consists of rotational energy levels that are correlated to the deformed GROUND STATE of the nuclei. The deformation is the result of perturbations and influences, including Coriolis forces, “beta vibrations”

(“breathing”) and “gamma vibrations.” In this model, the NUCLEUS has energy formats that are considered as fluids. For an IRROTATIONAL FLOW in a “spheroidal drop,” the energy levels will be lowest (see Figure Y.9).

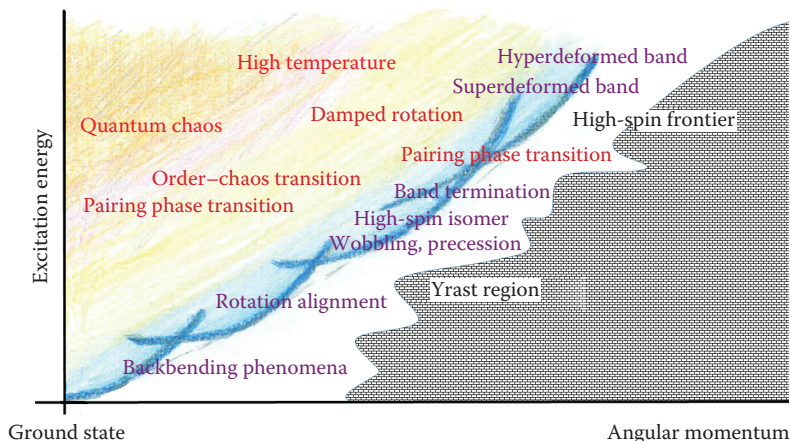


Figure Y.9 Yrast region; representative under extreme cold conditions.

Yrast state

[nuclear] In the nuclear structure, there are ENERGY levels associated with WAVE MOTION and momentum. The yrast state represents the lowest energy in the nuclear structure for a given angular momentum (see Figure Y.10).

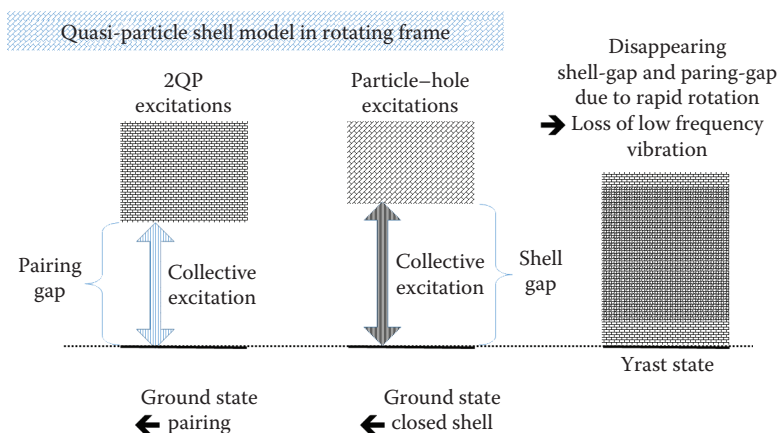


Figure Y.10 Yrast state.

Yukawa, Hideki (1907–1981)

[computational, energy, general, thermodynamics] Theoretical physicist from Japan. Hideki (also Hideky) Yukawa predicted the pi-meson (PION) in 1932 (also known as the Yukawa particle), which was experimentally verified in 1960 by the Brazilian scientist CÉSAR MANSUETO GIULIO LATTES (1924–2005). Hideki Yukawa's reasoning was that the strong interaction (hadron–hadron interaction) had to be mediated by the exchange of a virtual BOSON of relatively a large size (quantum-mechanically spoken, based on energy–mass equivalence), the virtual meson pi. The pi meson is a QUARK—antiquark composite PARTICLE. Hideki Yukawa received the Nobel Prize in Physics in the year 1949 (see [Figure Y.11](#)).



Figure Y.11 Hideki Yukawa (1907–1981). (Courtesy of Amon Carter Museum of American Art, Forth Worth, TX.)

Yukawa potential

[computational, energy, general, thermodynamics] For the atomic NUCLEUS the nuclear forces can be described as suspended in a POTENTIAL WELL, defined by HIDEKI YUKAWA (1907–1981) in 1932. The Yukawa potential describes the one-pion exchange potential, based on the transfer of one MESON from one NUCLEON to another, where the interaction potential energy (U_p) between the nucleons separated at a DISTANCE r with the respective strength g_* is defined as $U_p = -g_*^2 (e^{-\mu_m r} / r) \cong Q / 4\pi r$, where $\mu_m = mc / \hbar$ (an operator in the

SCHRÖDINGER EQUATION), with m the REST MASS, $c = 2.99792458 \times 10^8$ m/s the speed of LIGHT, Q the collective charge, and $\hbar = h/2\pi$, with $h = 6.62606957 \times 10^{-34}$ m²kg/s the PLANCK'S CONSTANT (see Figure Y.12).

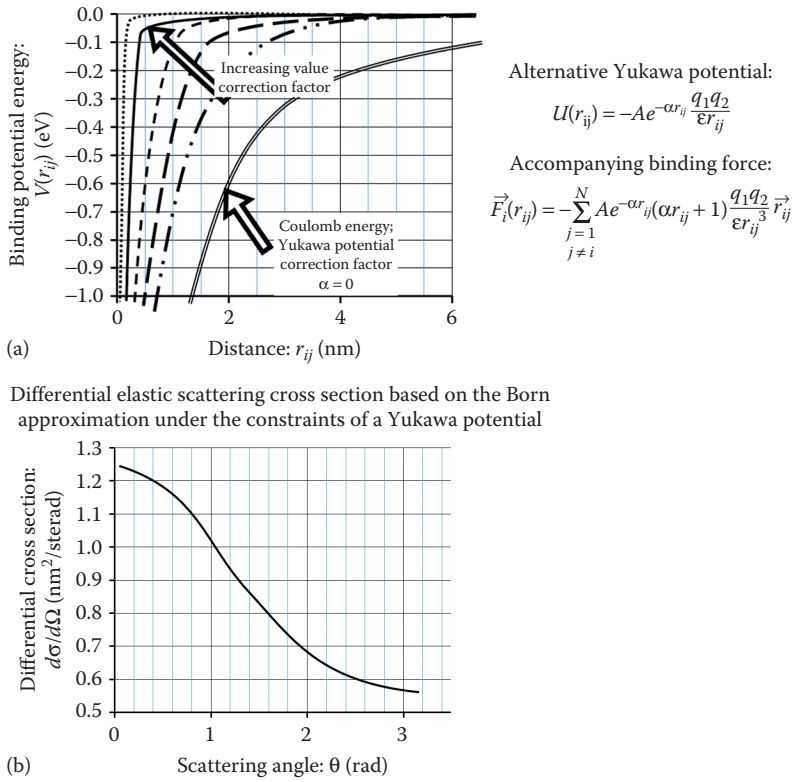


Figure Y.12 (a) Yukawa potential and (b) scattering cross section under the Yukawa potential.



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Z

Z Boson

[general] Product of the DECAY process for a NEUTRON, delivering a Z-particle and a PROTON; subject to WEAK interaction under the GAUGE THEORY. The Z-particle is a neutral VECTOR BOSON. All vector bosons are W^+ , W^- , and Z^0 . The mass for the Z-vector bosons is slightly more than the W-boson, $91 \text{ GeV}/c^2$, with $c = 2.99792458 \times 10^8 \text{ m/s}$ the speed of LIGHT. Z-particles are subject to the Yang–Mills GAUGE FIELD interaction and are highly unstable (decay time $\tau_d = 10^{-24} \text{ s}$) and decay into an electron–electron-antineutrino pair. The Z-particle was introduced in 1961 by SHELDON LEE GLASHOW (1932–), a pupil of the theoretical physicist from the United States Julian Schwinger (1918–1994) (Nobel Laureate [1965]), known for his discovery of the charged W-bosons a few years earlier. Glashow received a Nobel Prize for his work on his discovery of the fourth QUARK, the CHARM quark, and other elementary PARTICLE work, specifically the GRAND UNIFIED THEORY applied to the WEAK FORCE and electromagnetic interaction in 1979, along with STEVEN WEINBERG (1932–) and Abdus Salam (1926–1996) (also see **W-PARTICLE**) (see [Figure Z.1](#)).

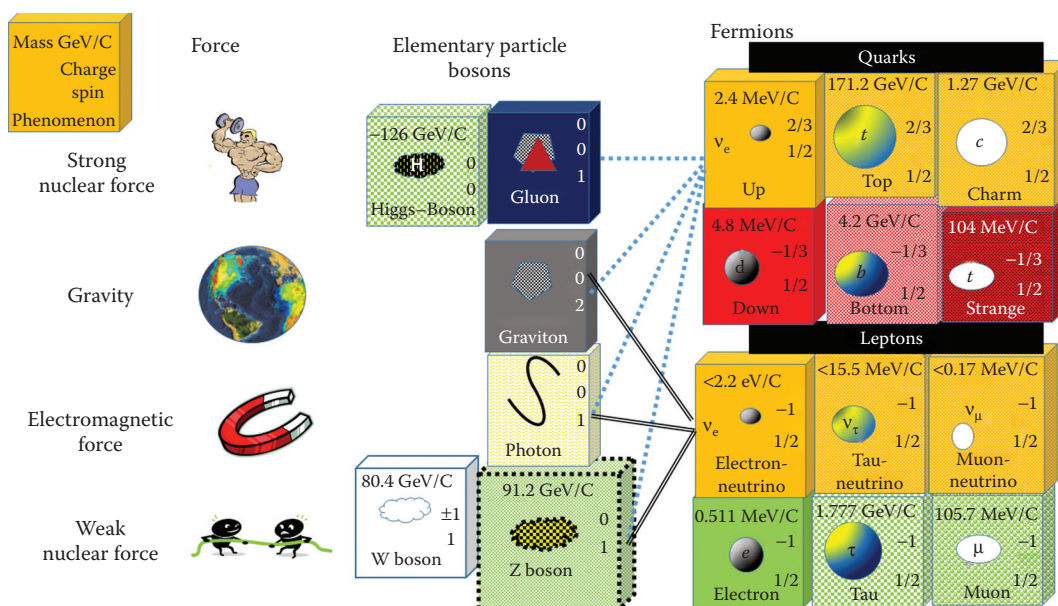


Figure Z.1 Representation of the concept of the Z-boson.

Zartman, Ira Forry (1899–1981)

[atomic, nuclear] Scientist from the United States who provided a detailed description of NEUTRON source FISSION processes. Ira Zartman also provided a theoretical description of the NUCLEAR FISSION process (see [Figure Z.2](#)).



Figure Z.2 Ira Forry Zartman (1899–1981).

Zeeman, Pieter (1865–1943)

[atomic, general, nuclear] Physicist from the Netherlands. The work of Pieter Zeeman illustrated the influence of an external MAGNETIC FIELD on the ATOMIC EMISSION lines of excited ELEMENTS, described under the ZEEMAN EFFECT. Zeeman had access to a power MAGNET and a fine DIFFRACTION GRATING, and experimented with the spectral emissions from a sodium flame (see [Figure Z.3](#)).



Figure Z.3 Pieter Zeeman (1865–1943).

Zeeman and Stark effect

[atomic, general, nuclear] ENERGY split in atomic electron transitions based on influences from magnetic fields modified by JOHANNES STARK (1874–1957) in 1913 based on the work of PIETER ZEEMAN (1865–1943) in 1896 (see ZEEMAN EFFECT and STARK EFFECT).

Zeeman effect

[atomic, computational, general, nuclear, quantum] ENERGY split in atomic electron transitions based on influences from magnetic fields. Introduced by PIETER ZEEMAN (1865–1943) in 1896. With several similarities to the STARK EFFECT (1913), this phenomenon is also known as the Zeeman–Stark effect, where the German scientist JOHANNES STARK (1874–1957) used an external electric field. When sending the emissions of the sodium LIGHT SOURCE through a DIFFRACTION GRATING under the exposure of an external steady-state MAGNETIC FIELD the D-line of the sodium emission was found to be split in constituent components. When an excited atomic state is exposed to an external magnetic field, the emission lines with respect to the unperturbed SOLUTION reveal a split that is associated with the ORBITAL ANGULAR MOMENTUM of the respective electron as well as the respective ELECTRON SPIN. This is different than the LAMB SHIFT. The phenomenon is dominated by the QUANTUM mechanical definition of ATOMIC ENERGY states. According to PETER DEBYE (1884–1966) and ARNOLD SOMMERFELD (1868–1951), the splitting of the spectral lines was associated with the orbital MAGNETIC QUANTUM NUMBER. The orbital “MAGNETIC” quantum number (m_ℓ) under the influence of an external magnetic field can assume values that are derived from the orbital ANGULAR MOMENTUM QUANTUM NUMBER (ℓ) ranging from $m_\ell = -\ell, (-\ell+1), \dots, (\ell-1), \ell$, hence splitting the field-free emission line for ℓ into a range of closely spaced lines associated with the orbital quantum number m_ℓ , using the quantization of the magnetic field in the z -direction (the axis of precision) as $L_z = m_\ell \hbar = m_\ell (h/2\pi)$, with $h = 6.6261 \times 10^{-34}$ J s the PLANCK’S CONSTANT; note that the orbital angular momentum quantum number (ℓ) is limited by the PRINCIPAL QUANTUM NUMBER (n ; $n: 1, 2, 3, \dots$). The energy difference (ΔE) between the states with different ORBITAL MAGNETIC MOMENT under the influence of the small perturbation provided by the applied magnetic field yields the following split: $\Delta E = g_L \mu_B m B = (\langle \mu_{Lz} \rangle + \langle \mu_{Sz} \rangle) B$, with $g_L = 1 + [J(J+1) + S(S+1) - L(L+1)]/2J(J+1)$ the Landé’s factor, J the TOTAL ANGULAR MOMENTUM, indicated by the QUANTUM NUMBER j , S the spin angular momentum (with quantum number m_s), and L the total orbital angular momentum, with the EIGENVALUE $L = \ell(\ell+1)\hbar^2$; $\mu_B = e\hbar/2m_e$ the Bohr magneton, with m_e the electron mass; m the quantum number of the z -component of the magnetic moment and B the MAGNITUDE of the external magnetic field and $\langle \mu_{Lz} \rangle$, respectively $\langle \mu_{Sz} \rangle$, the z -components of the average respective magnetic moments. The magnetic moments are $\mu_{Lz} = (e/2m_e)\sqrt{L(L+1)}\hbar \cos\theta_L \cos\theta$ and $\mu_{Sz} = (e/2m_e)\sqrt{S(S+1)}\hbar \cos\theta_S \cos\theta$, with $\theta = m_J/\sqrt{J(J+1)}$ and θ_L the ANGLE of the total orbital angular momentum with the total angular momentum and θ_S the angle of the SPIN angular momentum with the total angular momentum. The energy splitting between states depends on the quantum numbers for the respective states. In a transition between two singlet states, the spin angular momentum will be zero for both and the three remaining conditions are $m_J = -1; 0; +1$, which is considered the NORMAL ZEEMAN EFFECT. Under the condition that $S \neq 0$, L can change in accordance with the selection rules (nuclear and atomic transition selection rules: $n > l$; $j = \ell \pm (1/2)$; $m_\ell: 0, \pm 1, \pm 2, \dots, \pm \ell$; $m_j: -j, -j+1, \dots, 0, \dots, j-1, j$; $m_s = \pm(1/2)$), which contribute to

changes in g_L , providing a convoluted energy configuration and these transitions are referred to as the ANOMALOUS ZEEMAN EFFECT (*also see* PAULI EXCLUSION PRINCIPLE *and* FINE STRUCTURE) (see Figure Z.4).

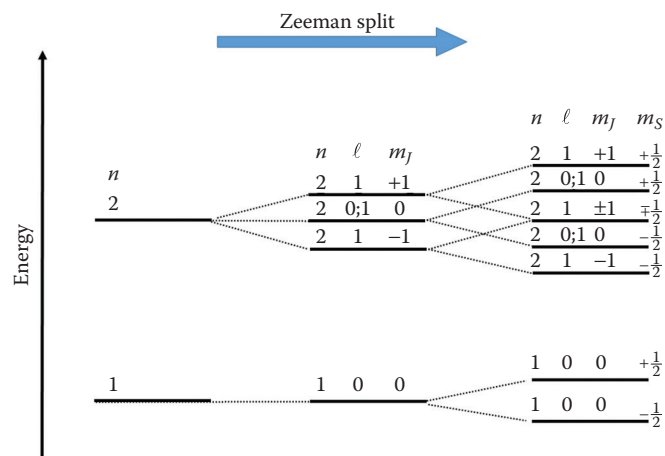


Figure Z.4 Zeeman effect.

Zehnder, Ludwig (1854–1949)

[optics] Optical physicist from Switzerland. Best known for the development of the Mach–Zehnder INTERFEROMETER in collaboration with ERNST MACH (1838–1916) (see Figure Z.5).



Figure Z.5 Ludwig Zehnder (1854–1949).

Zeiss, Carl (1816–1888)

[optics] Scientist and entrepreneur from Germany. In 1840, Carl Zeiss started a corporation building optical devices that had set the standard for most optical technology offered, initially starting out with the fabrication of high quality lenses. The corporation was located in the city of Jena, which has an excellent resource for components to produce quality glass. The market switched from large APERTURE microscope lenses to CAMERA lenses as the popularity of the camera increased. In 1872, ERNST ABBE (1840–1905) joined the group. Abbe used the WAVE properties of LIGHT to increase the accuracy of LENS design, specifically with respect to RESOLUTION (*also see* ABBE CONDITION). The GLASS quality was further improved through the contributions of the material expert Otto Schott (1851–1935) in 1885 (see [Figure Z.6](#)).

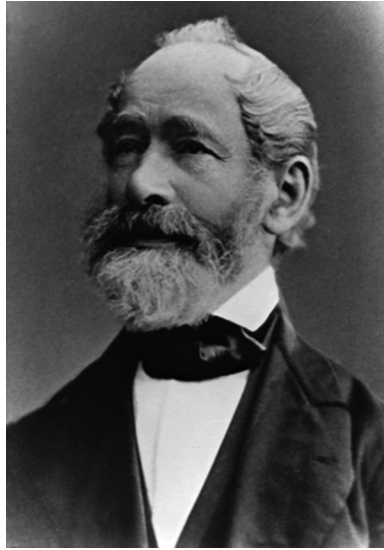


Figure Z.6 Carl Zeiss (1816–1888). (Courtesy of Carl Zeiss Archives, Carl Zeiss Microscopy GmbH, Jena, Germany.)

Zenith

[astrophysics/astronomy, computational, geophysics] “Straight above.” The highest point reached by a celestial object in its orbit with respect to the observer’s frame of reference. Also used to define the moment in time when an observation or a phenomenon is most likely to occur (see [Figure Z.7](#)).

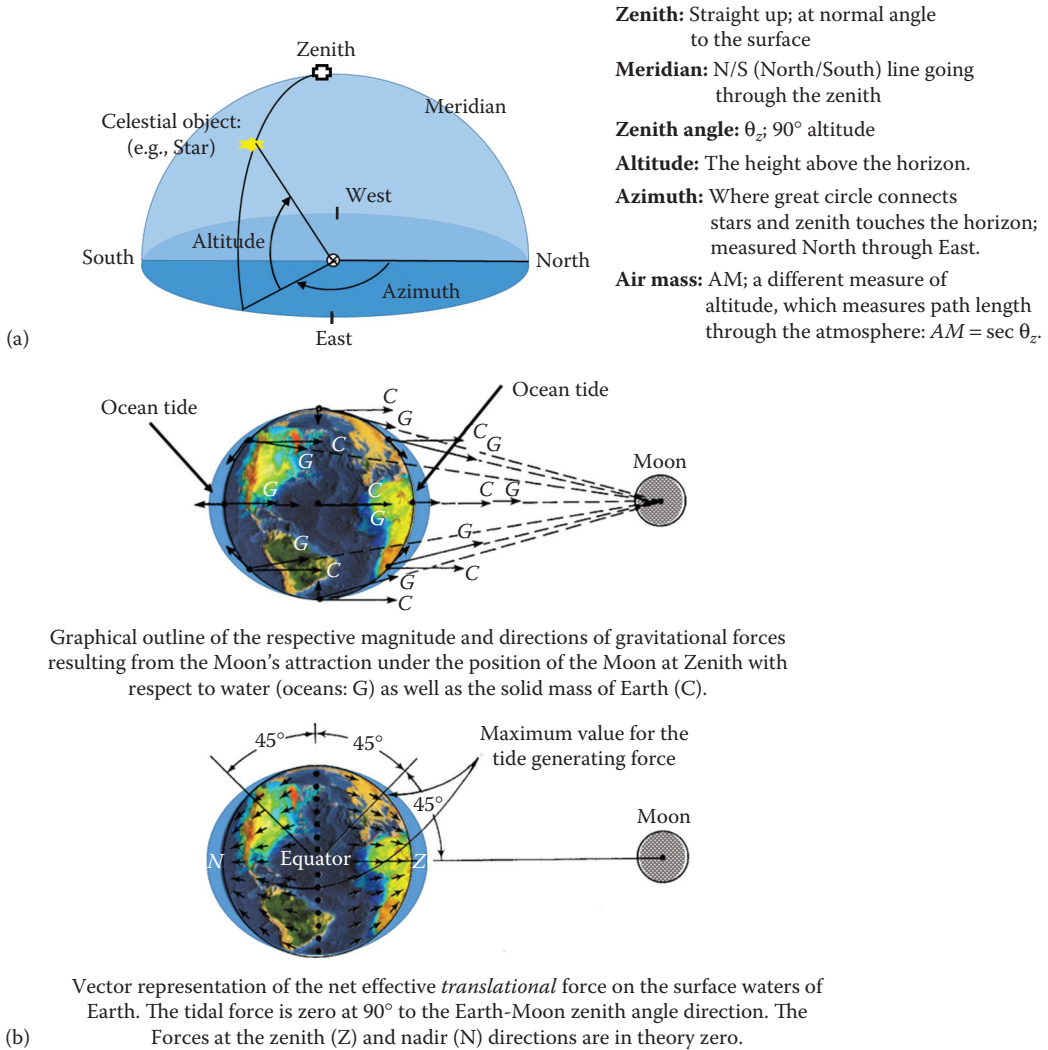


Figure Z.7 Zenith. (a) Angular definition and (b) influence of zenith angle position of the Moon on the tidal force vector.

Zenith angle

[astrophysics/astronomy, computational, geophysics] Angle elapsing directly overhead, in spherical coordinates designated as φ , alternatively: ϕ . The angle with respect to the horizon measured in the vertical direction. In comparison, the azimuth angle is measured in the “horizontal” plane. The zenith angle is frequently used to describe the solar angle; specifically with respect to the seasons (see Figure Z.8).

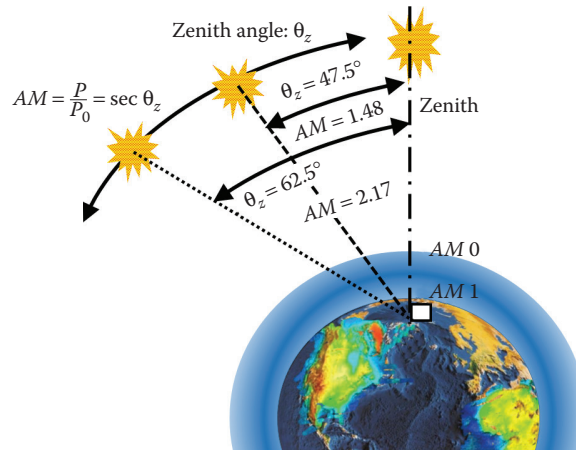


Figure Z.8 Zenith angle.

Zero-entropy state

[thermodynamics] In a diagram or graphical representation of the entropy states of a system as a function of boundary conditions, the state with the lowest entropy is referred to as the zero-entropy state. From a thermodynamic standpoint, there are no lower states, which makes the GROUND STATE zero plausible. Classical MECHANICS can often be considered a special case of THERMODYNAMICS: zero-entropy PHYSICS (see Figure Z.9).

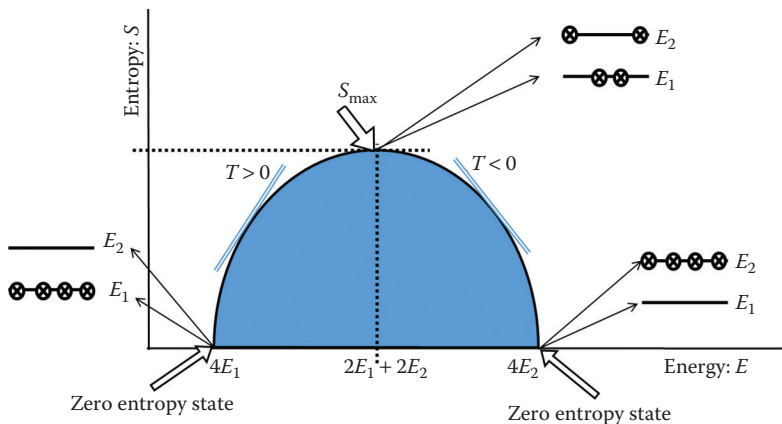


Figure Z.9 Graphical representation of the Zero-entropy state; keeping in mind that the third law of thermodynamics “predicts” that for a crystalline substance at $T = 0\text{K}$, the entropy will as per the definition be equal to zero ($S = 0$). Diagram of the entropy for a system with four particles composed of two energy levels, described as a function of the total energy. The entropy is zero when all the particles are in either the lowest energy state or the highest state, whereas the entropy has a maximum value when the energies are split 50/50.

Zero-equation model

[computational, fluid dynamics] In computational FLUID DYNAMICS, the special case of turbulent models that can be addressed by algebraic equations only are considered zero-equation TURBULENCE models. The conditions and circumstances can be derived directly from the supplied parameters. As such, these models may not be able to account for the history of a process nor account for DIFFUSION or convection phenomena. The primary zero-equation model is for steady-state boundary layers, the simple viscous model, which requires no integration or differentiation. Two well-known zero-equation models are the “Baldwin–Lomax” model and the “Cebeci–Smith” model. The Baldwin–Lomax model provides the eddy viscosity for a two-layer system as a function of the local BOUNDARY LAYER velocity profile. The process separates the layer in an inner and an outer layer, where the inner layer has a fixed viscosity defined by Prandtl, and the outer region has a different constant value primarily derived from force equilibrium states. In the Cebeci–Smith model the viscosity is also derived from the velocity profile; however, in this case, it uses the averaged kinetic profile for the inner layer (using the first-order derivative for location as velocity) with pressure gradient, whereas the outer region makes an approximation by introducing a “velocity thickness” as a virtual constant layer.

Zero-G

[general] Hypothetical effective weightlessness. Obtained in the apparent or true absence of gravitational attraction. An airplane in free fall will create a condition of zero GRAVITY on the internal frame of reference. In reality, there are always gravitational forces acting, no MATTER how small, from distant planets, stars, and galaxies, or just another HUMAN BODY or SATELLITE. Even galaxies provide gravitational attraction on each other, forming complex and contorted “pin wheel” constructions ranging over thousands of light-years; there are several sets of three or more galaxies that have been imaged as a “set” (see [Figure Z.10](#)).



Figure Z.10 Zero-G; weightlessness: ultimate zero-G in the outer space.

Zero-mass particles

[general, quantum] Particles with zero mass can theoretically only exist at the speed of LIGHT. Examples of zero-mass particles are photons and neutrinos as well as gravitons. The GRAVITON is the theoretical PARTICLE mediating the gravitational interaction in an orbit around the objects between which the gravitational attraction is experienced. In this hypothetical case, the (quantum mechanical) graviton forms an ENERGY field rather than just an existence of mass. The graviton model resembles the chemical attraction in a MOLECULE that shares one or MOLE electrons. The zero-mass follows from the “rest energy,” which equals the momentum multiplied by the speed of light.

Zero-point energy

[atomic, nuclear] The lowest ENERGY of a system under QUANTUM mechanical conditions. Under the UNCERTAINTY PRINCIPLE, even a single particle out by itself in the outer space does not have zero kinetic energy; based on the definitions of the uncertainty principle, the PARTICLE will have zero-point energy. Alternatively, at the ABSOLUTE ZERO temperature, 0.000000000000000 K, theoretically there will be no MOTION and hence no discernable energy content, although the particle does exist and hence it has (quantum-mechanical) probabilities associated with it, as well as motion of the nuclei and orbiting electrons. The latter makes the case purely theoretical, with no physical means of achieving the true absolute zero Kelvin. Under zero-point energy conditions, electromagnetic RADIATION is still allowed. This ELECTROMAGNETIC ENERGY density can reach excessive values, theoretically up to 10^{58} J/m^3 (see Figure Z.11).

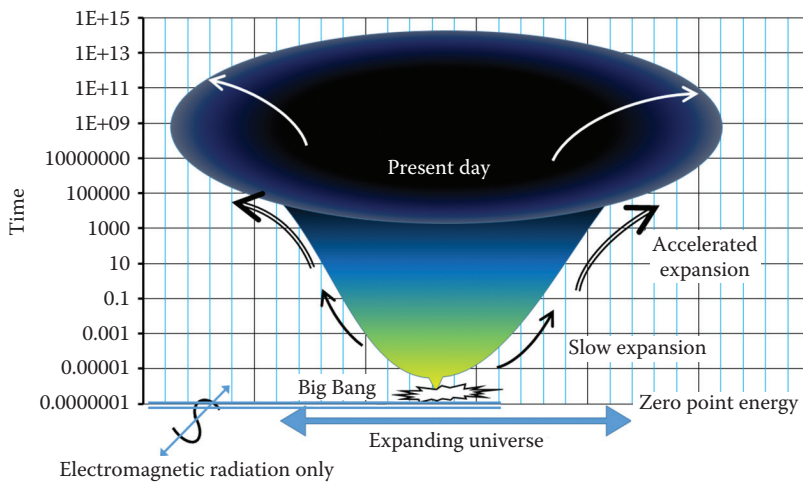


Figure Z.11 Zero-point energy.

Zero-temperature state

[thermodynamics] Ground ENERGY state for the constituents of the system, within a volume, which by definition has entropy zero and temperature zero. In physical terms, a temperature of ABSOLUTE ZERO Kelvin would mean that all MOTION has stopped and there is no energy in the system; all electron and nuclear motions would have come to a complete but hypothetical halt.

Zeroth law of thermodynamics

[general, thermodynamics] Concept introduced by JOSEPH BLACK (1728–1799) around 1760. The concept entails that when two materials of unequal temperature are brought in contact with each other they will both gradually reach a uniform equilibrium temperature (see THERMODYNAMICS, ZEROTH LAW).

Zhukovsky, Nikolay Yegorovich (also: Joukowsky; Николай Егорович Жуковский) (1847–1921)

[computational, fluid dynamics] Scientist and mathematician from Russia. Nikolay Zhukovsky contributed to the mathematical description of aerodynamic LIFT pertaining to flight. His work led to the implementation of the rounded frontal tip on a WING based on his theoretical analysis as well as the sharp tip on the rear to create a flow that exits without TURBULENCE. He also established the first aerodynamic institute near Moscow.

His other work includes the WATER–HAMMER equation, which is also known as the JOUKOWSKY EQUATION (see [Figure Z.12](#)).



Figure Z.12 Nikolay Yegorovich Zhukovsky (also: Joukowski; Николая Егорович Жуковский) (1847–1921) in 1915.

Zweig, George (1937–)

[energy, general, quantum, relativistic] Physicist from the Russian Federation (USSR; Union of Soviet Socialist Republics. Russian СССР Союз Советских Социалистических Республик, English translation: Soyuz Sovetskikh Sotsialisticheskikh Respublik). George Zweig along with MURRAY GELL-MANN (1929–), provided evidence that baryons (as well as the other HADRON group: mesons) are not primary ELEMENTARY PARTICLES. Dr. Zweig was a pupil of RICHARD FEYNMAN (1918–1988) (see [Figure Z.13](#)).

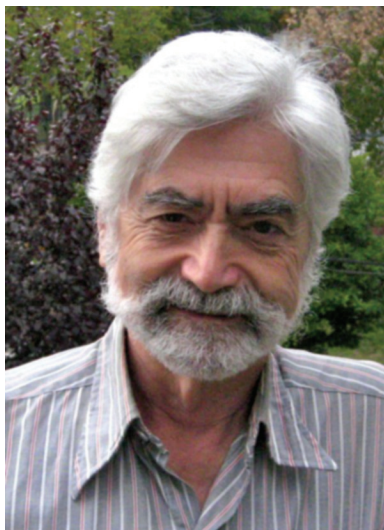
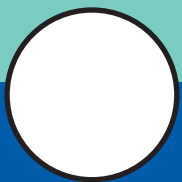


Figure Z.13 George Zweig (1937–). (Courtesy of CERN, Centre Européenne pour la Recherche Nucléaire, European Organization for Nuclear Research, Zurich, Switzerland.)



Appendix A

Common physical constants

Avogadro's number: $N_A = 6.022140857(74) \times 10^{23} \text{ mol}^{-1}$

Boltzmann coefficient: $k_b = 1.38064852(79) \times 10^{-23} \text{ m}^2 \text{ kg} / \text{s}^2 \text{ K}$

Coulomb's constant: $k_C = (1/4\pi\epsilon_0)$, where: $\epsilon_0 = 8.854187817... \times 10^{-12} \text{ C}^2 / \text{Nm}^2$ the permittivity of free space

Electron charge: $k_e = 8.987551787... \times 10^9 \text{ Nm}^2 / \text{C}^2$

Electron Compton wavelength: $\lambda_C = 2.426312367(11) \times 10^{-12} \text{ m}$

Electron mass: $m_e = 9.10938356(11) \times 10^{-31} \text{ kg}$

Faraday constant: $F = 96485.3365 \text{ sA/mol} = 9.648533289(59) \times 10^4 \text{ C/mol}$

Gas constant: $R = 8.3144621(75) \text{ J/Kmol}$

Gravitation constant: $G = 6.67408(31) \times 10^{-11} \text{ Nm}^2 / \text{kg}^2 = 6.67408(31) \times 10^{-11} \text{ m}^3 / \text{kg s}^2$

Permeability of free space: $\mu_{E0} = 1.2566370614... \times 10^{-6} \text{ H/m}$

Permittivity of free space: $\epsilon_{EM0} = 8.854187817... \times 10^{-12} \text{ C}^2 / \text{Nm}^2$

Planck's constant: $h = 6.626070040(81) \times 10^{-34} \text{ m}^2 \text{ kg/s}$, $\hbar = (h/2\pi)$

Proton mass: $m_p = 1.672621898(21) \times 10^{-27} \text{ kg}$

Rydberg constant: $R_y = \frac{2\pi^2 k_b^2 e^4 m_e Z^2}{h^3 c} = \frac{10973731.568508(65) \text{ m}^{-1}}{Z=1}$

Speed of light: $c = \sqrt{\mu_0 \epsilon_0}^{-1} = (\mu_0 \epsilon_0)^{-1/2} = 2.99792458 \times 10^8 \text{ m/s}$

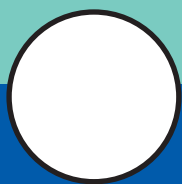
Stefan-Boltzmann constant: $\sigma_{SB} = 5.670367(13) \times 10^{-8} \text{ W/m}^2 \text{ K}^4$



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Appendix B

Notable physicists

Ernst Karl Abbe (1840–1905)
George Biddell Airy (1801–1892)
Hannes Olof Gösta Alfvén (1908–1995)
Alhazen, Abū ‘Alī al-Ḥasan ibn al-Ḥasan ibn al-Haytham (965–1040)
Lorenzo Allievi (1856–1941)
André Marie Ampère (1775–1836)
Anders Johan Ångström (1841–1874)
Knut Johan Ångström (1857–1910)
Aristotle (384–322 BC)
Aristocles (better known as Plato) (427–347 BC)
Archimedes (287–212 BC)
Svante August Arrhenius (1859–1927)
Pierre Victor Auger (1899–1993)
Lorenzo Romano Amedeo Carlo Avogadro (1776–1856)
Francis Bacon (1561–1626)
Antoine Henri Becquerel (1852–1908)
Alexander Graham Bell (1847–1922)
George Irvine Bell (1926–2000)
Daniel Bernoulli (1700–1782)
Jean-Baptiste Biot (1774–1862)
Niels Henrik David Bohr (1885–1962)
Ludwig Eduard Boltzmann (1844–1906)
Napoleon Bonaparte (1769–1821)
Max Born (1882–1970)
Matthew Boulton (1728–1809)
Robert Boyle (1627–1691)
William Henry Bragg (1862–1942)
William Lawrence Bragg (1890–1971)
Tycho Brahe (1546–1601)
Robert Bunsen (1811–1899)
Augustin Louis Cauchy (1789–1857)
John Calley (1644–1725)
Nicolas Léonard Sadi Carnot (1796–1832)
Giovanni Domenico Cassini (1625–1712)
Anders Celsius (1701–1744)
Sir James Chadwick (1891–1974)
Subrahmanyan Chandrasekhar (1910–1995)
Jacques Alexandre César Charles (1746–1823)
Rudolf Julius Emmanuel Clausius (1822–1888)
Henry Cavendish (1731–1810)
Arthur Holly Compton (1892–1962)

Nicolaus Copernicus (alias of Niclas Koppernigk) (1473–1543)
Charles Augustin de Coulomb (1736–1806)
Manya (Marie) Skłodowska Curie (1867–1934)
Pierre Curie (1859–1906)
Jean-Baptiste le Rond d'Alembert (1717–1783)
Leonardo da Vinci (1452–1519)
Louis Jacques-Mandé Daguerre (1787–1851)
John Dalton (1766–1844)
Charles Robert Darwin (1809–1882)
Clinton Joseph Davisson (1881–1958)
Prince Louis Victor Pierre Raymond duc de Broglie (1892–1987)
Lee de Forest (1873–1961)
Carl Gustaf Patrik de Laval (1845–1913)
Pierre de Maricourt (1220–1290)
Henri de Mondeville (1260–1320)
Petrus (Peter) Josephus Wilhelmus Debye (1884–1966)
René Descartes (1596–1650)
Henri-Alexandre Deslandres (1853–1948)
Paul Adrien Maurice Dirac (1902–1984)
Frederick Donnan (1870–1956)
Christian Johann Doppler (1803–1853)
Charles François de Cisternay du Fay (1698–1739)
Pierre Louis Dulong (1785–1838)
Karl Theodore Dussik (1908–1968)
Thomas Edison (1847–1931)
Albert Einstein (1879–1955)
Leonard Euler (1707–1783)
Daniel Gabriel Fahrenheit (1686–1736)
Michael Faraday (1791–1867)
Enrico Fermi (1901–1954)
Richard P. Feynman (1918–1988)
Armand Hippolyte Louis Fizeau (1819–1896)
Sir John Ambrose Fleming (1849–1945)
Jean Bernard Léon Foucault (1819–1868)
Benjamin Franklin (1706–1790)
Joseph von Fraunhofer (1787–1826)
Augustin-Jean Fresnel (1788–1827)
Otto Frisch (1904–1979)
Buckminster Fuller (1895–1983)
Claudius Galenus [Galen] (130–201)
Galileo Galilei (1564–1642)
Luigi Galvani (1737–1789)
Johann Carl Friedrich Gauss {Gauß} (1777–1855)
Joseph Louis Gay-Lussac (1778–1850)
Johannes Geiger (1822–1945)
William Gilbert (1540–1603)
Josiah Willard Gibbs (1839–1903)
Lester Halbert Germer (1896–1971)
David E. Goldman (1910–1998)
Francesco Maria Grimaldi (1618–1663)
Gotthilf Heinrich Ludwig Hagen (1797–1884)
George Ellery Hale (1868–1938)

Stephen Hawking (1942–)
Werner Karl Heisenberg (1901–1976)
Hermann Ludwig Ferdinand von Helmholtz (1821–1894)
Joseph Henry (1797–1878)
Heinrich Rudolf Hertz (1857–1894)
Gustav Ludwig Hertz (1887–1975)
Sir Alan Lloyd Hodgkin (1914–1998)
Robert Hooke (1635–1703)
Edwin Hubble (1889–1953)
Sir Andrew Fielding Huxley (1917–2012)
Christiaan Huygens (1629–1695)
Constantijn Huygens (1596–1687)
Carl Gustav Jacob Jacobi (1804–1851)
Hans Jansen (early/mid-sixteenth century–early seventeenth century); *also* Hans Martens
Zacharias Jansen (1580–1638)
James Prescott Joule (1818–1889)
Heike Kamerlingh Onnes (1853–1926)
William Thomson, 1st Baron Kelvin (Lord Kelvin) (1824–1907)
Johannes Kepler (1571–1630)
Gustav Robert Kirchhoff (1824–1887)
Diederik Johannes Korteweg (1848–1941)
(Joseph Louis) Giuseppe Luigi comte de Lagrange (1737–1813)
Sir Horace Lamb (1849–1934)
Willis Eugene Lamb (1913–2008)
Johann Heinrich Lambert (1728–1777)
Adrien-Marie Legendre (1752–1833)
Pierre-Simon de Laplace (1749–1827)
Max Theodor Felix von Laue (1879–1960)
Antoine Laurent de Lavoisier (1743–1794)
Ernest Orlando Lawrence (1901–1958)
Sir John Edward Lennard-Jones (1894–1954)
Joseph Liouville (1809–1882)
Hans Lipperhey (1570–1619)
Aleksandr Mikhailovich Lyapunov (1857–1918)
Colin Maclaurin (1689–1746)
Hendrik Antoon Lorentz (1853–1928)
Ernst Mach (1838–1916)
Pierre Pelerin de Maricourt (AKA Peter Peregrine) (c. 1220–1270)
Ernest Marsden (1889–1970)
James Clerk Maxwell (1831–1879)
Maria Goeppert-Mayer (Göppert) (1906–1972)
Gustav Mie (1869–1957)
Dmitri Ivanovich Mendeleev (1834–1907)
Albert Abraham Michelson (1852–1931)
Robert Andrews Millikan (1868–1953)
Henry de Mondeville (1260–1320)
Earle Gordon Moore (1929–)
Edward Morley (1838–1923)
Henry Gwyn Jeffreys Moseley (1887–1915)
Henry Mosley (1887–1915)
Rudolf Ludwig Mössbauer (1929–2011)
Robert Sanderson Mulliken (1896–1986)

Edward Aloysius Murphy, Jr. (1918–1990)
 Pieter van Musschenbroek (1692–1761)
 Claude-Louis Navier (1785–1836)
 Walther Hermann Nernst (1864–1941)
 Thomas Newcomen (1664–1729)
 Sir Isaac Newton (1642–1727)
 Paul Gottlieb Nipkow (1833–1940)
 Harry Theodor Nyquist (“Nyqvist”) (1889–1976)
 Hans Christian Oersted (1777–1851)
 Georg Simon Ohm (1787–1854)
 Heike Kamerlingh Onnes (1853–1926)
 Robert J. Oppenheimer (1904–1967)
 Denis Papin (1647–1712)
 Blaise Pascal (1623–1662)
 Alexis Petit (1791–1820)
 Max Karl Ernst Ludwig Planck (1858–1947)
 Plato (427–347 BC)
 Jules Henry Poincaré (1854–1912)
 Jean-Louis Léonard Marie Poiseuille (1799–1869)
 Siméon Denis Poisson (1781–1840)
 Ludwig Prandtl (1875–1953)
 Claudius Ptolemaeus (also: Ptolemy) (approx. 90–168 AD)
 Ptolemy (c. 90–168 AD)
 Wolfgang Ernst Pauli (1900–1958)
 Oscar Raab (1876–1986)
 Isidor Isaac Rabi (1898–1988)
 Sir Chandrasekhara Venkata Raman (1888–1970)
 William John Macquorn Rankine (1820–1872)
 Rembrandt van Rijn (1606–1669)
 Olaus (Ole) Christensen Rømer (Roemer) (1644–1710)
 Ernest Rutherford (1871–1937)
 John William Strut, the 3rd Baron Rayleigh (1842–1919)
 Osborn (Osborne?) Reynolds (1842–1912)
 Wilhelm Conrad Röntgen (1845–1923)
 Count Rumford (1753–1814), Benjamin Thompson
 Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson
 Johannes Robert Rydberg (1854–1919)
 Wallace Clement Sabine (1868–1919)
 Joseph Sauveur (1653–1716)
 Félix Savart (1791–1841)
 Arthur Leonard Schawlow (1921–1999)
 Paul Scherrer (1890–1969)
 Sir Franz Arthur Friedrich Schuster (1851–1934)
 Thomas Savery (1650–1715)
 Erwin Schrödinger (1887–1961)
 Sir Franz Arthur Friedrich Schuster (1851–1934)
 Karl Schwarzschild (1873–1916)
 Thomas Johann Seebeck (1770–1831)
 Arnold Johannes Wilhelm Sommerfeld (1868–1951)
 Johannes Stark (1874–1957)
 Ernest Starling (1866–1927)
 Joseph Stefan (1835–1893)

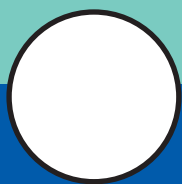
Sir George Gabriel Stokes, 1st Baronet (1819–1903)
Jacques Charles François Sturm (1803–1855)
Brook Taylor (1685–1731)
Edward Teller (1908–2003)
Nikola Tesla (1856–1943)
Thales of Miletus (c. 624–c. 546 BC; known as Thales: Θαλῆς)
Joseph John Thomson (1856–1940)
Charles Hard Townes (1915–)
Evangelista Torricelli (1608–1647)
Rudolf Snel van Royen (Snellius) (1546–1613)
Willebrord Snel van Royen (Snellius) (1591–1626)
Robert Jemison van de Graaff (1902–1967)
Johannes Diderik van der Waals (1837–1923)
Jacobus Henricus van 't Hoff (1852–1911)
Urban le Verrier (1811–1877)
Andreas Vesalius (1515–1564)
Leonardo da Vinci (1452–1519)
John Hasbrouck Van Vleck (1899–1980)
Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)
James Watt (1736–1819)
Sir Charles Wheatstone (1802–1875)
John Archibald Wheeler (1911–2008)
Thomas Young (1773–1829)
Carl Zeiss (1816–1888)



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Appendix C

Acoustics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
27,000 BC	Lin-Lun	Huang-Zhong pipe, “calibrated musical tone,” designed by Lin-Lun from bamboo under the reign of the Chinese Yellow Emperor Huangdi. The musical range of sound was further separated into 12 standard pitch pipes.
2,000 BC	Fohi	First documented attempt to correlate pitch and sounds produced by “the five elements: earth, water, fire, air, and wind.”
~500 BC		Greek empire scientific division of sounds into three tone “genders:” chromatic, diatonic, and enharmonic, very similar to the present day musical classification. This musical note organization was derived from Arab influences who based their knowledge on Hindu influences dating back several centuries.
~500 BC	Pythagoras (570 BC–497 BC)	Definition of a single note generated as the result of the air motion with the same “frequency” as the reverberating body. Pythagoras paved the way for the musical definition in octaves (double-frequency segmentation) with mathematical formulation. Pythagoras also derived that the “sharpness” of the tone produced by a reverberating string is inversely proportional to its length, that is, frequency (pitch).
~350 BC	Aristotle (384 BC–322 BC)	Description of the movement of air under the influence of a vibrating body.
240 BC	Chrysippus (279 BC–206 BC)	Forming an analogy to water waves, the Greek philosopher Chrysippus derived that the waves on the string of the lute form a sound wave propagating in air with similar patterns of perturbation.
25 BC	Marcus Vitruvius Pollio (ca. 80 BC–15 BC)	Description of the use of vases in the amphitheaters that will attenuate low frequency sound, similar to current day acoustic baffles used in architecture. First documented use of architectural acoustic design.
1500	Leonardo da Vinci (1452–1519)	Description of the requirements of a medium to transmit sound. Da Vinci also made the same correlation between water waves and sound waves as the Greek philosopher Chrysippus (near 2,000 years prior). Leonard da Vinci also derived that sound has a distinct velocity of propagation.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1636	Marin Mersenne (1588–1648)	First scientific description of the audible tone, specifically 84 Hz. Marin Mersenne also introduced the formal concept of the octave and measured the velocity of sound
1638	Galileo Galilei (1564–1642)	Publication of <i>Mathematical Discourses Concerning the New Sciences</i> providing a definition of sound and frequency similar to that of his contemporary Marin Mersenne, but apparently independently derived.
1640	Pierre Gassendi (1582–1655)	Argument that sound was a stream of “particles” (atoms) emitted from a body. This concept was not accepted and is not in line with observations and deductions made over the past millennia.
1650	Francesco Maria Grimaldi (1613–1663)	Correlation between light wave refraction and similar aspect of visible and audible (mechanical) waves.
1660	Robert Boyle (1626–1691) and assistant Robert Hooke (1635–1703)	Experimental verification of the Leonardo da Vinci’s argument for the requirement of a medium by means of an evacuated chamber with a ticking clock inside.
1678	Robert Hooke (1635–1703)	Mathematical representation of force and deformation, providing the fundamentals for vibration and elastic theory.
1700	Joseph Sauveur (1653–1713)	Introduction of the word “acoustics” derived from the Greek word for sound. Joseph Sauveur actually was a deaf–mute and provided significant contributions to the present day understanding of acoustic concepts. Sauveur introduced the concepts of fundamental wave, harmonics, node, next to ventral segment.
1816	René-Théophile-Hyacinthe Laennec (1781–1826)	Inventor of the stethoscope, using a wooden horn to amplify the sound originating from a beating heart. Note that the use of animal horns for the collection of weak sounds (spoken word) has been recorded centuries prior to the beginning of the western calendar (before Christ; BC, even millennia BC).
1836	Ernst Florence Friedrich Chladni (1756–1827)	Discovered torsional vibrations. His work advanced acoustical engineering and acoustical architecture.
1842	Christian Andreas Doppler (1803–1853)	Introduction of the “Doppler effect,” defining the change in perceived frequency of a wave (or other periodic event) for an observer and source moving relative to each other.
1845	Simon Ohm (1789–1854)	Introduction of the discrete concepts in hearing for the ear. Simon Ohm hypothesized that there are individual segments in the ear that respond to only a single sine wave frequency, the ear separates sound in its fundamental frequency and harmonics by mechanical means.
1847	James P. Joule (1818–1889)	Discovery of the magnetostrictive effect; paving the way for ultrasonic imaging.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1863	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Foundations for spectral analysis of sound.
1877	Lord Rayleigh (1842–1919) [John William Strutt]	Theoretical publication on the physical aspects of acoustics; publication: <i>Theory of Sound</i> . Lord Rayleigh also introduced the mechanical (destructive) force associated with the cavitation aspect of sound. Cavitation would fall under fluid dynamics in the theoretical sense.
1880	Paul-Jacques Curie (1855–1941) and Pierre Curie (1859–1906)	Further evidence supporting the evolution of ultrasonic imaging with the discovery of electric charges emerging on the surfaces of certain crystals which are subjected to pressure or tension (shear or normal stress). This is referred to as the piezoelectric effect.
1900–1915	Wallace Clement Sabine (1868–1919)	Fundamental revisions to acoustical design. Established the Riverbank Acoustical Laboratories in Geneva, Illinois.
1910	Sir Horace Lamb (1849–1934)	Wave mechanics: Lamb wave. Theory of sound. Horace Lamb also contributed to hydrodynamic descriptions (1895).
1920–1930	Paul Earls Sabine (1879–1958) and son Hale Johnson Sabine (1909–1981)	Noise control and architectural acoustic design.
1937	Karl Theo (Theodore) Dussik (1908–1968)	Ultrasonic imaging.
1920–1940	Harvey Fletcher (1884–1990)	Introduction of quantifying the perception of sound and mechanical waves in the Bell Telephone Laboratories; referred to as “psychoacoustics.” Introduction of the loudness concept and the decibel as a quantity for sound magnitude. Harvey Fletcher also introduced the first electronic hearing aid device.
~1940	Harry F. Olson (1902–1982)	Loudspeaker design and definition for the reproduction of sound from electronic sources.
~1954	Georg von Békésy (1899–1972)	Fundamental description of the mechanism of action in human hearing.
1964	Warren P. Mason (1900–1986)	Revolutionized the concept of ultrasound imaging. Refinements to soft-tissue imaging and work on three-dimensional reconstruction. The combination of different transducers enhances the resolution and can yield additional material-specific information.

Astronomy

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
13.8 billion years BC	Georges Henri Joseph Édouard Lemaître (1894–1966) and Edwin Powell Hubble (1889–1953)	“The Big Bang,” in 1927 the expanding universe was recognized.
30,000 BC		Early human’s impression of the heavens, drawings of eclipses, comets, specifically the drawing of a supernova, such as the Pueblo Petrograph.
4,500 BC	Carnac Stones	Arrangement of menhirs depicting the solar system in a rudimentary fashion, specifically the sun and the moon positions.
3,100 BC	Stonehenge	Neolithic (preceding the Bronze Era) astronomical abacus used for calculating the positions of planets and the occurrence of the changes in the Sun with respect to Earth: solstice. Alleged connection with the Druids of King Arthur’s court.
ca. 2,800 BC		Mesopotamian astronomers use the moon as a guide for calendar development: lunar calendar. The Mesopotamian calendar has 354 days.
ca. 2,700 BC		Astronomers in Sumeria evolve the lunar calendar in a solar year.
1,600 BC	Babylonia	Recordings of planets, comets; the elliptical orbits time of transition, transcribed on clay tablets (this type of record keeping is referred to as cuneiform).
1,581 BC	King Ammizaduga of Nivevah (mid-eastern; Mesopotamia; stretching out into northern Africa, Europe, reaching out into Pakistan and Western Russia)	Description of scientific methodology used by the Babylonian astronomers. Detailed description of the orbital motion for the planet Venus.
~500 BC	Hellenistic culture	The ancient Greeks using astronomical records which they inherited from the Babylonians to generate a <i>cosmological framework</i> . Data was used for both practical goals, such as navigation, in addition to predicting future experiments. This may be interpreted as the introduction of the concept of the “natural philosopher.” The Greek word “astronomy” refers to “law and order.” The word expresses the attempts to seek order in the surroundings of the earth. The Greek combined the words: ἀστρονομία from ἄστρον astron, describing the concept of “star” and -νομία -nomia from νόμος nomos, meaning “law.”

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~580 BC	Thales (c. 624 BC–546 BC)	Greek astronomer who used the Babylonian data to predict the recurrence and orbital trajectories of solar eclipses.
~355 BC	Plato (424 BC–348 BC)	
~350 BC	Aristotle (384 BC–322 BC)	Geocentric model for the solar system.
330 BC	Heraclides (387 BC–312 BC)	First recorded scientific model of the “solar system” as a geocentric configuration. This initiated the debate of the geocentric versus heliocentric configuration. The orbits of all the planets were considered perfect spheres based on the assumption that the universe was “perfect” and with little data available to prove otherwise.
270 BC	Aristarchus [of Samos] (310 BC–230 BC)	Introduction of the heliocentric model for the earth’s solar system.
220 BC	Eratosthenes (276 BC–194 BC)	The early Greeks derived that the Earth is a sphere based on the observed shadow of Earth on the Moon during lunar eclipses. Eratosthenes calculated the circumference of Earth (not using the mathematics outlined by Pythagoras (570 BC–495 BC)) using the length of the shadow in two location in Greece; at Syene the stick casts no shadow, while the shadow at the same time in Alexandria had a certain length. The value of the circumference derived by Eratosthenes of 40,320 km (252,000 stadia; 1 stadia = 0.16 km) while the current accepted circumference at the equator is 40,030 km.
150 BC	Hipparchus (190 BC–120 BC)	First recorded star catalog, including the names of constellations.
150 AD	Ptolemy (90–168)	Librarian of Alexandria who reintroduced the geocentric theory of Heraclides and formulated a complete description of the solar system that explained as well as predicted the apparent planetary motions using the combined data from centuries of observations on planetary motions. The mathematical model of Ptolemy was very complex and difficult to use to describe the elliptical orbits. The approximation used circles upon circles, requiring more than 28 circle combination to define the orbital patterns. The solution to retrograde motion explained the orbits of the planets by means of epicycles and deferents. The primary orbit is the deferent, the perturbation orbit is the epicycle.
ca. 1000	Mohammed ibn al-Hasan (Alhazen) ‘Abu Ali’ ibn al-Haytham al-Basra (965-1039) [Iraq, Egypt]	Mathematical descriptions in optics and astronomy. The work of Al Hazen anticipated Newton’s First Law of Motion {Sir Isaac Newton (1643–1727)}; the “principle of least action.”
1054	China	Crab Nebula is the remnant of a star that was observed to explode by Chinese astronomers. The Crab Nebula is located at a distance of 6,523 light years from earth.
5th century–15th century		Dark Ages; geocentric Ptolemy model.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
4th century–7th century		Renaissance.
1500	Nicolaus Copernicus (1473–1543)	Reintroduction of the heliocentric planetary model for earth. Challenging the doctrine of the Roman Catholic Church. Copernicus still used circular orbits.
1580	Tycho Brahe (1546–1601)	Construction of an observatory in Denmark. Tycho Brahe used a sextant and trigonometry to analyze the planetary orbits and derived their elliptical orbits. Telescopes were not available during his lifetime.
ca. 1600	Galileo Galilei (1564–1642)	Described laws of motion (falling bodies; gravitational acceleration) and inertia, before Sir Isaac Newton (1643–1727). Invented the pendulum clock and many more engineering feats. Additional contributions by Galileo Galilei are in astronomy, specifically the discovery of Jupiter's moons. Galileo also wrote about infinite equinumerosity, what is known as the “Hilbert's Hotel Paradox” (David Hilbert (1862–1943); “Hilbert Space”). Galileo once wrote “Mathematics is the language in which God has written the universe.”
1600	Johannes Kepler (1571–1630)	Refinements to the models introduced by his mentor Tycho Brahe on the elliptical orbits. Formulation of the “laws of planetary motion,” beginning of the conceptual introduction of the “clockwork universe.”
1603	Johann Bayer (1572–1625)	Introducing named stars for their constellation by Greek letters, in “Uranometria” in the approximate order of (apparent) radiance “brightness,” for example, Alpha Centauri.
1609		Introduction of the first telescope.
~1620	Galileo Galilei (1564–1642)	Introduction of laws of motion. Recorded observations of the universe with the first telescopes (refracting). Providing conclusive evidence for the heliocentric solar system, challenging the long-lasting geocentric solar system model. Galileo's observations led to the discovery that the sky filled with light is constructed of a multitude of stars, in our direct vicinity forming the Milky Way. He also discovered that the planet Jupiter has moons, the sun has “sun spots,” and that the moon has a surface profile that is not flat (valley's and mountains).
1661	Johann Hevelius (1611–1687)	Published “Sternverzeichniss,” the “meaning”/description of stars.
1666	Sir Isaac Newton (1643–1727)	Description of the spectral composition of the sunlight using a prism.
1679	Edmond Halley (1656–1742)	Publication of the first southern star catalog.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1680	Sir Isaac Newton (1643–1727)	Universal law of gravitation. Introduced the first reflecting telescope and formulated the theory of light.
1712	John Flamsteed (1646–1719)	<i>Historia Coelestis Britannica</i> , edited by Edmond Halley. This catalog introduces the Flamsteed Number, labeling stars (e.g., 21 Tauri).
1731	John Bevis (1693–1771)	Description of the Crab Nebula has been discovered near the star Z Tauri. John Bevis was at that time making his Stellar Atlas, which was published in the year 1786.
1750	Leonhard Euler (1707–1783)	Most prolific mathematician in the known history of mathematics. Euler developed the polyhedral theorem (with some suspicion that this may be traced back to René Descartes (1596–1650). Euler revolutionized the design of pumps based on his fluid dynamic theories, including turbine equations. Other theoretical interests of Leonhard Euler were optics, astronomy, acoustics, mechanics, and music. In his astrophysics work, he developed a formulation to determine the moon orbit in a three body motion problem; first ever. Additional theoretical efforts defined the rotational motion of rigid bodies of various configurations. Euler also introduced the definition for the square root of negative one as the letter “i”, next to several other mathematical standard expressions for algebraic terms. Leonard Euler also introduced the exponential expression with the use of the complex number by means of sin and cosine: $e^{ix} = \cos x + i \sin x$. Euler popularized the use of the letter Sigma for a series summation.
1781	Charles Messier (1730–1817)	Recording of the Crab Nebula in the Messier catalogue as Number 1. The total catalogue contained 103 entries.
1782	William Herschel (1738–1822)	Published catalogue of 2500 celestial objects, including 269 double stars.
1799	Pierre Simon, Marquis de Laplace (1749–1827)	Laplace Law; Laplace transform to solve complex equations and his work on celestial mechanics (astrophysics).
1818	Joseph Fraunhofer (1787–1826)	Description of the solar spectrum, recognizing 576 dark lines. The more prominent lines were labeled with letters A to K. He also discovered that the light reflecting from the Moon and planets displayed spectral features that were also in that of the solar spectrum; furthermore that the spectra of planets differ from the solar spectrum. Joseph Fraunhofer designed and used the diffraction grating, one of which had the astounding (for the time) 3,625 lines per centimeter.
1832	David Brewster (1781–1868)	Spectra of cold gases produce dark absorption lines in continuous spectra.
1841	John W. Draper (1811–1882)	First picture made of the Moon. Picture made by J. W. Draper on Daguerre plates.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1845	William Parsons (1800–1876)	Lord William Parsons, 3rd Earl of Rosse (1800–1876) discovers the spiral pattern of M51, and subsequently for the M99 nebulae classification (Messier scale) and 13 other “nebulae” which were since known as “spiral nebulae.”
1847	John W. Draper (1811–1882)	Discovery that hot solids emit light in continuous spectra, and in contrast, hot gases produce line spectra.
1857	Joseph von Fraunhofer (1787–1826) Carl August von Steinheil (1801–1870) William Lassell's (1799–1880)	Start of large size, high quality, reflector telescope construction and use. Telescope optics was notably improved by Joseph von Fraunhofer (1787–1826) with the development of the achromatic objective in 1824, this initiated the construction of larger refractor telescopes up to the Yerkes 102 cm. The reflector techniques followed significant improvement from the invention of glass mirrors by Carl August von Steinheil (1801–1870) in 1857 when constructing a 10 cm reflector, which was succeeded by the 33-cm reflector telescope developed by Michel Foucault (1926–1984), and the 60-cm glass mirrors of Lassell telescope named after William Lassell (1799–1880). Most big telescopes of the twentieth century are reflector telescopes made with glass mirrors. The first telescope exceeding Lord William Parsons, 3rd Earl of Rosse's (1800–1876) Leviathan of 1845, with 1.8 m opening, in aperture was the 2.54m diameter Mount Wilson telescope constructed 1917, followed by the Palomar telescope with diameter of 5.08 m in 1948, and the Zelenchukskaya telescope with diameter of 6.1 m in 1976, with only partial success unfortunately.
1852–1859	Friedrich Wilhelm Argelander (1799–1875)	Elaboration on the Messier catalog, containing the magnitude (radiance) and relative positions of 324,000 stars in the Bonner Durchmusterung. this is translated from German with liberal interpretation: the “Elaboration performed at Bonn”; the city Bonn in Germany (Die Rheinische Friedrich-Wilhelm-Universität Bonn) had instated a new observatory, designed by Friedrich Wilhelm Argelander.
1845–1890	Adalbert Krüger (1832–1896) and Eduard Schönfeld (1828–1891)	Collaborators. Introduction of the Star Catalogue: “Bonner Durchmusterung.” Comprehensive outline of the stellar configuration.
1859	Gustav Robert Kirchhoff (1824–1887) and Robert Bunsen (1811–1899)	Discovery that characteristic spectrum of lines are resulting from individual chemical element (and compound), where the lines are at the same respective wavelengths in emission spectra and alternatively absorption spectra. Hence the chemical composition of any light source, including celestial bodies (both stars and planets from which light is reflecting), can be resolved from spectral analysis. Robert Kirchhoff published the initial chemical constitution of the Sun in 1859.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1861	Karl Friedrich Zöllner (1834–1882)	Introduction of the to-date most accurate and quantifiable photometer used for classifying stellar object.
1863	Anders Jonas Ångström (1818–74)	Publication of the map of the Solar spectrum, identifying of lines corresponding chemical elements.
1864	John Herschel (1792–1871)	Published General Catalog of more than 5,000 nonstellar objects.
1864	William Huggins (1824–1910)	Discovery of gaseous nebulae spectra and found them to be emission line spectra. This observation provided as simple and unique criterion distinguishing the nebulae from star clusters. Star clusters, on the other hand, similar to the stars that composing, show a continuous spectrum (in which absorption and sometimes emission lines appear overlaid). Spiral “nebulae,” however, show continuous spectra similar to stars.
1868	William Huggins (1824–1910)	Based on the work by Christian Doppler (1803–1853) describing the shifting spectral lines with respect to moving bodies, outlined how this should effect the galactic spectroscopy and that spectral lines of moving celestial objects should appear shifted. The first measurements affirming this effect were obtained in 1888 by Hermann Carl Vogel (1841–1907).
1872	Henry Draper (1837–1882)	First spectral photograph of the star Vega.
1876	Father Angelo Secchi (1818–1878)	Spectroscopic classification of first classification of 316 stars.
1880	John Louis Emil Dreyer (1852–1926)	J. L. E. Dreyer’s New General Catalogue (NGC), building on the Messier Catalogue. The NGC lists over 13,0000 stellar and nonstellar objects.
1900	Cornelius Easton (1864–1929)	Description of the Milky Way as a spiral nebula, with the earth’s solar system at a distance of approximately 8000 pc (parsec; 1 pc $\approx$ 3.26 light-years) from its center.
1906	Karl Schwarzschild (1873–1916)	Model development and publication for the solar atmosphere from theory of thermodynamical equilibrium. Description of the equation of radiative transfer.
1907		Potsdamer Durchmusterung; star catalog compiled in Potsdam, Germany.
1904–1908	Karl Schwarzschild (1873–1916)	Göttinger Aktinometrie; theoretical description of the radiance with respect to galactic location, stellar energy, and angular perception.
1914–1924	Harvard Observatory	Henry Draper Catalogue, describing the spectral profiles of 225,300 stars; referring to Henry Draper (1837–1882), pioneering astrophotography and associated spectral analyses.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1924	Edwin Powell Hubble (1889–1983)	Definition of the outer part of the Andromeda “Nebula (M31)” consisting of stars and found novae and Cepheid variables, in this manner it was established to be an external galaxy or star system.
1926	Bertil Lindblad (1895–1965) and Jan Oort (1900–1992)	definition of the theory of kinematics and dynamics of the Milky Way galaxy.
1929	Edwin Powell Hubble (1889–1983)	Derivation of distance–red shift relation for galaxies. Theoretical description of the expansion of the universe.
1951		Discovery of the 21-cm radio radiation emerging from galactic neutral hydrogen, which provided further supporting evidence for the spiral shape of the Milky Way.
1963	Maarten Schmidt (1929–)	Discovery of the first Quasar.
1957		Sputnik 1 (USSR) first artificial satellite.
1961		Venera 1 (USSR) first mission to another planet (Venus).
1969		Apollo 11 (USA) first men land on the Moon.
1972	Stephen Hawking (1942–), Jacob Bekenstein (1947–)	Thermodynamics of black holes.
1976		Viking 1 and 2 (USA) first successful unmanned landing on Mars.
1979		Voyager 1 and 2 (USA) fly by Jupiter.
1980–1981		Voyager 1 and 2 fly by Saturn.
1981		First space flight of the (NASA) Shuttle space orbiter.
1986		Voyager 2 fly by of Uranus.
1989		Voyager 2 fly by of Neptune.
1990		Hubble Space Telescope (USA/ESA) launched.
1998		Initiation of the construction of the International Space Station in outer space orbiting earth.
2011		Last space flight of the Space Shuttle space orbiter program.

Atomic

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 550 BC	Thales of Miletus (ca. 640 BC–546 BC)	Documented the magnetic attractive properties of rubbed amber and of lodestone.
ca. 450 BC	Leucippus (5th century BC)	Proposed an atomic concept of matter.
ca. 400 BC	Democritus of Abdera (ca. 460 BC–357 BC)	Student of Leucippus, one of the most famous of the atomists in ancient times. Democritus stated: “The only existing things are the atoms and empty space; all else is mere opinion.”
ca. 335 BC	Aristotle (384 BC–322 BC)	Proposing that all matter was basically composed of the same “equal” continuous primordial material.
ca. 300 BC	Epicurus of Samos (ca. 342 BC–270 BC)	Philosophical system based on the atomism hypothesis expressed by Democritus.
ca. 300 BC	Zeno of Cition (ca. 336 BC–264 BC)	Foundation of the Stoic school of philosophy, based on the premise that matter, space, and natural phenomena were continuous.
ca. 60 BC	Titus Lucretius Carus (ca. 96 BC–55 BC)	Formulation explaining natural phenomena by implementation of the beliefs of Democritus and Epicurus. His poem: “De Rerum Natura,” is the most comprehensive record of the Greek atomism stream of thought. The atomism of ancient times was primarily a metaphysics concept. The atomic view of matter in the modern interpretation was introduced only in its most elementary form by the beginning of the nineteenth century.
ca. 400	Saint Augustine (Aurelius Augustinus) (354–430)	Documentation of the impression that the forces exerted by rubbed amber (electric) and by lodestone (magnetic) are fundamentally different properties.
ca. 1600	William Gilbert (1540–1603)	First detailed study of magnetism and additionally for electrical phenomena showed that, in addition to amber, many other materials can be electrical charged (electrified).
1638	Galileo Galilei (1564–1642)	Description of two additional sciences with respect to “mechanics” and “local motions” in the publication: “Discors e Dimostrazioni Matematiche intorno a due nuove Scienze attenti alla Mecanica e Movimenti locali” (<i>Discourses and Mathematical Demonstrations</i>). This establishes Galileo Galilei as the founder of dynamics, with fall-out to atomic and particle physics.
1650–1700	Robert Boyle (1627–1691), Robert Hooke (1635–1703), and Sir Isaac Newton (1642–1727)	Qualitative explanations of Boyle’s gas law, assuming an indivisible unit forming the basis for the gas (the unknown atom), by assuming a kinetic theory of gases.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1675	Jean Picard (1620–1682)	Observation of a luminous glow (radiation) in the Torricellian vacuum of a mercury barometer resulting from the motion of the mercury when the instrument was transported.
1675	Sir Isaac Newton (1642–1727)	Introduction of the corpuscular theory of light.
1705	Francis Hauksbee (1666–1713)	Construction and operation of a powerful electrostatic generator and documented discovery of the conditions producing luminous electric discharges in gases.
1731	Stephen Gray (1666–1736)	Discovery of the electrical conduction principles.
1734	Charles Francois De Cisternay du Fay (1698–1739)	Showed that there are two kinds of electrification: resinous and vitreous, and then proposed a two-fluid theory of electric discharge. He also found that the air in the vicinity of a hot body is conducting.
1752	Benjamin Franklin (1707–1790)	Experimentally verification of the hypothesized electrical nature of lightning and introduced the one-fluid theory of flow for the concept of electricity—from surplus of positive to deficiency or negative (assuming flow of positive charges). The theory of Ben Franklin contained the first essential statement of the law of conservation of electric charge.
1753	John Canton (1718–1772)	Discovery of electrostatic induction.
1766	Henry Cavendish (1731–1810)	Discovery of hydrogen. Cavendish described the inverse square law of force action between electric charges and significant additional laws of electricity but unfortunately he largely withheld announcement of his experimental observations. The work by Henry Cavendish was not known until James Clerk Maxwell (1831–1879) published his papers in 1879.
1785	Charles Augustin Coulomb (1736–1806)	Definition of the law of force between electric charges.
1789	Antoine Laurent Lavoisier (1734–1794)	Publication of the particle aspect for chemical elements and the verification of the law of conservation of matter in chemical reactions.
1791	Bryan Higgins (1737–1820) and William Higgins (1769–1825)	Documentation of the first of a series of experiments resulting in the formulation of the laws of chemical combination.
1799	Joseph Louis Proust (1754–1826)	Introduction of the law of definite proportions for chemical compounds.
1803	John Dalton (1766–1844)	Publication of the first of a series of papers introducing the concept of atomic weights. Additional statements established the law of multiple proportions, and specifically introducing the atomic theory of matter.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1811	Lorenzo Romano Amedeo Avogadro (1776–1856)	Introduction of Avogadro's hypothesis and differentiation between atoms and molecules.
1813	Jons Jacob Berzelius (1779–1848)	Introduction of the presently known and used system of symbols for the chemical elements.
1815	William Prout (1875–1850)	Hypothesis that all elements are composed of an integral number of hydrogen atoms, described by Henry Cavendish (1731–1810) in 1766.
1815–1820	Joseph Fraunhofer (1787–1826)	Noted the spectral lines of several elements, obtained the first grating spectra, and observed the Fraunhofer (absorption) lines in solar spectra. Indication of the future recognition of the energy levels in the atomic structure (electron orbits) of elements.
1819	Pierre Louis Dulong (1785–1838) and Alexis Therese Petit (1791–1821)	Recognized the law of constancy of molar specific heat capacities of elements.
1820	Hans Christian Ørsted [Oersted] (1777–1851)	Discovery that an electric current produces a magnetic field. This revelation initiated the study of electromagnetism.
1821	Thomas Johann Seebeck (1770–1831)	Discovery of thermoelectricity.
1823	Andre Marie Ampere (1775–1836)	Published his mathematical theory of electromagnetism and the laws of magnetic field produced by currents. Some of these laws were also discovered independently by Jean-Baptiste Biot (1774–1862) and Félix Savart (1791–1841).
1826	Georg Simon Ohm (1787–1854)	Introduction of Ohm's law.
1827	Robert Brown (1773–1858)	Discovery of the concept of Brownian movement.
1833	Michael Faraday (1791–1867)	Discovery of electrolysis and introduced the terms “anode” and “cathode,” with the associate flow of electrical charges.
1850–1900	August Karl Krönig (1822–1879), Rudolf Julius Emanuel Clausius (1822–1888), James Clerk Maxwell (1831–1879), Ludwig Boltzmann (1844–1906), and Josiah Willard Gibbs (1839–1903)	Kinetic theory of gases. Introduction of statistical mechanics. James Clerk Maxwell derived the velocity distribution law in 1860, Emanuel Clausius introduced the thermodynamic concept of entropy in 1865, and Ludwig Boltzmann related entropy to thermodynamic probability in 1877.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1858	Stanislao Cannizzaro (1826–1910)	Redefined the conflicting values of atomic weights by clarifying the terms “atomic,” “molecular,” and “equivalent” weights.
1859	Heinrich Geissler (1814–1879) and Julius Plucker (1801–1868)	Discovery of the “particle rays” (now known as cathode rays) from the negative electrode in gaseous discharge tubes, what we current know are electrons.
1860	Robert Wilhelm Eberhard Bunsen (1811–1899) and Gustav Robert Kirchhoff (1824–1887)	Recordings of the emission spectra of alkali metals in flames. Recognition of dark lines in the spectrum arising from absorption when illuminated by a bright light source through the flame. These dark lines are identical to the spectral lines observed in the solar spectrum observed by William Hyde Wollaston (1766–1828) and Joseph von Fraunhofer (1787–1826) in 1803: Fraunhofer lines, and it was argued that these lines in the sunlight are due to the absorption of light by gases in the solar atmosphere that are cooler than those “emitting the light” (not much was known about the mechanism of action of the sun), based on contemporary knowledge an oxidizing gas produces light.
1863	James Alexander Reina Newlands (1837–1898)	Stated the law of octaves for chemical structures, a limited and elementary form of the periodic table of the elements.
1865	Joseph Loschmidt (1821–1895)	Application of the equations of the kinetic theory of gases to allow for the first determination of Avogadro’s number and of molecular diameters.
1869	Dmitri Ivanovich Mendeleev (1834–1907) and Julius Lothar Meyer (1830–1895)	Both independently introduced the periodic table of the elements, a concise summary of years of documented experimental and theoretical chemistry. The table is both heuristic and mnemonic.
1869	Johann Wilhelm Hittorf (1824–1914)	Observation of the deflection of cathode rays in a discharge tube, by means of a magnetic field.
1871	Cromwell Fleetwood Varley (1828–1883)	Recognition that the cathode rays are negatively charged.
1874	Jacobus Hendricus van’t Hoff (1852–1911) and Joseph Achille Le Bel (1847–1930)	Description of the Carbon atom. Explanation of chirality (existence of two enantiomeric forms, virtually identical, but in actuality represent different molecules) based on the carbon atom asymmetry. Van’t Hoff introduces the four (4) different types of chemical bonds, all available for carbon based structures. These four separate chemical bonds provide the mechanism of action for the tetrahedron configuration, providing different three-dimensional atomic arrangements for the same chemical formula. This applies in particular to organic chemistry

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1876	Eugen Goldstein (1850–1930)	Introduction of the expression “cathode rays” and initiated experiments which eventually led to the discovery of the positive counterpart of the electron: Kanalstrahlen, meaning channel or canal rays. In 1886 Goldstein suggested that the aurora in the polar sky is due to cathode rays emerging from the sun, in fact these are a more complex range of ionizing particles.
1877	William Ramsay (1852–1916) next to Joseph Delsaulx (1828–1891), and Ignace J. J. Carbonelle (1829–1889)	Elaborated the first rather complete qualitative explanation of Brownian movement by attributing it to molecular impact. William Ramsay discovered several of the noble gases a few later, and he also made significant contributions to the study of radioactivity. He was awarded the Nobel Prize in Chemistry in 1904.
1879	William Crookes (1832–1919)	Initiated a series of experiments on the discharge of electricity through gases.
1881	Julius Elster (1854–1920), and Hans Friedrich Geitel (1855–1923)	Systematic investigation of the respective electrical effects produced by a broad range of incandescent solids.
1883	Thomas Alva Edison (1847–1931)	Recognition of the emission of negative electricity from incandescent filaments in a vacuum: Edison effect.
1884	Johann Jakob Balmer (1825–1898)	Derivation of an empirical relation for a spectral series of hydrogen as a function of wavelength. This was the first series equation found for any spectrum: Balmer series, linking atomic energy levels to spectral representations.
1887	Svante August Arrhenius (1859–1927)	Conclusively verified the ion dissociation theory of electrolytes which evolved from thermodynamic suggestions made by Rudolf Julius Emanuel Clausius (1822–1888) over the period 1850–1857. In 1903 Arrhenius was awarded the Nobel Prize in Chemistry.
1887	Heinrich Rudolph Hertz (1857–1894)	Description of the photoelectric effect while verifying the existence of the electromagnetic waves predicted by James Clerk Maxwell (1831–1879).
1888	Wilhelm Hallwachs (1859–1922)	Illustrated that only negative charges are emitted during the photoelectric effect.
1893	Philipp Eduard Anton Von Lenard (1862–1947)	Investigation of cathode rays by forcing them to pass through a Lenard window (thin window) tube into air. In 1905, Philipp Von Lenard was awarded the Nobel Prize in Physics for this and later work.
1895	Jean Baptiste Perrin (1870–1942)	Conclusively affirmation that cathode rays are negatively charged. In 1926 Jean Baptiste Perrin was awarded the Nobel Prize in Physics for this and later work.
1895	Wilhelm Conrad Roentgen (1845–1923)	Discovery of X-rays. Wilhelm Conrad Röntgen was awarded the Nobel Prize in Physics in 1901.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1896	Antoine Henri Becquerel (1852–1908)	Discovery of the radioactivity of the element uranium. He was awarded the Nobel Prize in Physics jointly with Marie Skłodowska Curie (1867–1934) and Pierre Curie (1859–1906) in 1903.
1896	Pieter Zeeman (1865–1943)	Observation of the splitting of spectral lines emitted by excited atoms while exposed to an intense external magnetic field. An earlier version of the theory of this effect was described by Hendrik Antoon Lorentz (1853–1928). They were jointly awarded the Nobel prize in Physics in 1902.
1897	Joseph John Thomson (1856–1940)	Determination of the electric charge value over the mass for cathode rays. In 1906 J. J. Thomson was awarded the Nobel Prize in Physics for this work.
1897	Ernest Rutherford (Lord Rutherford Of Nelson, 1st Baron) (1871–1937)	Experimental illustration that the radiation emitted by uranium was complex, consisting of “hard” (beta) rays as well as “soft” (alpha) rays. In 1908, Lord Rayleigh was awarded the Nobel Prize in Physics for this and for later work, he was awarded the Nobel Prize in Chemistry in 1908.
1898	Pierre Curie (1859–1906) and Marie Skłodowska Curie (1867–1934)	Isolation of the elements radium and polonium. They were awarded the Nobel Prize in Physics jointly with Antoine Henri Becquerel (1852–1908) in 1903. In 1911 Marie Curie was awarded the Nobel Prize in Physics for this work.
1899	Antoine Henri Becquerel (1852–1908), Stefan Meyer (1872–1949), Egon Von Schweidler (1873–1948), and Frederick Otto Giesel (1852–1927)	Independently observed the magnetic deflection of alpha and beta rays.
1899	Julius Elster (1854–1920) and Hans Geitel (1855–1923)	Experimental determination of the law of radioactive decay.
1899	Philipp Eduard Anton Von Lenard (1862–1947)	Experimental verification that photoelectric emission is due to electrons.
1899	Joseph John Thomson (1856–1940)	Explanation of the Edison effect is due to electrons.
1900	Antoine Henri Becquerel (1852–1908)	Experimental verification that beta rays are identical to the corpuscle character of cathode ray.
1900	Paul Villard (1860–1934)	Discovery of gamma rays.
1902	Philipp Eduard Anton Von Lenard (1862–1947)	Discovery of the photoelectric threshold frequency (i.e., minimum energy requirement) and additionally that the kinetic energy of photoelectrons is independent of the radiance of the incident light.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1903	Ernest Rutherford (Lord Rutherford of Nelson, 1st Baron) (1871–1937), and Frederic Soddy (1877–1956)	Illustrated that every radioactive process is a transmutation of elements. Frederic Soddy received the Nobel Prize in Chemistry in 1921.
1903	William Crookes (1832–1919), next to Julius Elster (1854–1920) and Hans Friedrich Geitel (1855–1923)	Uncovered that the luminescence produced when alpha particles strike zinc sulfide consists of discrete flashes of light of scintillations. This led to a method of counting individual alpha particles.
1904	William Ramsay (1852–1916) and Frederic Soddy (1877–1956)	Discovery of the remarkable recurrence of helium in all radium compounds.
1904	John Ambrose Fleming (1849–1945)	Application of the Edison effect to make the first thermionic valve (“radio” tube).
1904	Marian Von Smoluchowski (1872–1919)	Introduction of a statistical theory of Brownian movement.
1905	Albert Einstein (1879–1955)	Finalized the statistical theory of Brownian movement, based on the work of Marian Von Smoluchowski (1872–1919), introduction of the quantum explanation of the photoelectric effect, and published the special theory of relativity. Albert Einstein was awarded the Nobel Prize in Physics in 1921.
1905	Egon Von Schweidler (1873–1948)	Derivation of the law of radioactive decay based on probability theory, since it was not obtainable from causality.
1906	Owen Willans Richardson (1879–1959)	Series of important investigations regarding the emission of electricity from hot bodies: thermionic emission. Owen Willans Richardson was awarded the Nobel Prize in Physics in 1928.
1907–1912	Joseph John Thomson (1856–1940)	Devised methods of positive-ray analysis. These processes formed the beginning of mass spectroscopy.
1908	Charles Glover Barkla (1877–1944)	Discovery of the fact that the secondary X-rays of various elements are composed of groups of characteristic X-rays based on absorption experiments. Charles Barkla called these lines the K, L, and 117 radiations. He also demonstrated the polarization of X-rays. Charles Glover Barkla was awarded the Nobel Prize in Physics in 1917.
1908	Jean Baptiste Perrin (1870–1942)	Experimentally verification of several equations for Brownian movement. Perrin obtained more accurate values for Avogadro’s number, and illustrated that equipartition of energy is verified for small particles suspended in a stationary liquid.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1908–1910	Alfred Heinrich Bucherer (1863–1927), Karl Erich Hupka (1884–1919), Charles Eugene Guye (1866–1942), and Simon Ratnowsky (1884–1945)	Independent precision measurements of the mass of an electron as a function of the velocity of the electron. The results confirmed the Lorentz–Einstein mass variation relation.
1909	Ernest Rutherford (Lord Rutherford of Nelson, 1st Baron) (1871–1937) and Thomas Royds (1884–1955)	Experimentally illustrated that alpha particles are doubly ionized helium atoms, that is, helium nucleus.
1909–1910	Theodor Wulf (1868–1946) next to Albert Gockel (1860–1927)	Observation of charge leak rate from a highly insulated electroscope placed at the top of the Eiffel Tower, Paris, France, next to a study of the same effects in balloon ascents up to 4500 meters. The independent studies found the rate of leakage greater than at the surface of the earth. Their results were unexpected at the time because the effect at ground level had been attributed to local radioactivity of the soil.
1909–1911	Robert Andrews Millikan (1868–1953)	Introduction of the law of multiple proportions for electric charges and made the first precise assessment of the value for electronic charge: Millikan's oil-drop experiment. Robert Millikan was awarded the Nobel Prize in Physics in 1923.
1911	Peter Joseph Wilhelm Debye (1884–1966)	Application of the quantum theory to obtain a rather complete theory of specific heats, and subsequently applied the quantum concept to many problems and enigmas in physical chemistry. Peter Debye was awarded the Nobel Prize in Chemistry in 1936.
1911–1913	Ernest Rutherford (Lord Rutherford of Nelson, 1st Baron) (1871–1937), Johannes Geiger (1882–1945), and Ernest Marsden (1889–1970)	Their experiments pertaining to alpha-particle scattering by thin metal foils illustrated that a nuclear model of the atom was required in order to explain the energy interaction
1911	Charles Thomson Bees Wilson (1869–1959)	Construction of the first expansion cloud chamber, used for particle research. This is one of the most important device in nuclear physics. Charles Wilson was awarded the Nobel Prize in Physics jointly with Arthur Holly Compton (1892–1962) in 1927.
1912	Max Theodor Felix von Laue (1879–1960), Walter Friedrich (1883–1969), and Paul C. M. Knipping (1883–1935)	Affirmation of the wave nature of X-rays by crystal diffraction. Max Theodor Felix von Laue received the Nobel Prize in Physics in 1914.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1912	Hans Geiger (1882–1945), and John Mitchell Nuttall (1890–1958)	Heuristic law relating the energy of an emitted alpha particle from a nucleus to the disintegration constant of the parent nucleus.
1913	Hans Geiger (1882–1945)	Detailed description of the radiation discharge counter tube which was developed from a simpler form first made in 1908: Geiger counter. This instrument was further improved in 1928.
1913	Frederic Soddy (1877–1956) and Kasimir Fajans (1887–1975)	Radioactive decay laws of displacement in the periodic table for elements. Frederick Soddy introduced the term “isotopes.”
1913	George Charles De Hevesy (1885–1966) and Fritz Adolf Paneth (1887–1959)	Application of an isotope of lead: radium D, to study the solubility and the chemistry of lead compounds. This was the first documented use of an isotope as a tracer element. George De Hevesy received the Nobel Prize in Chemistry for his work in 1943.
1913	Neils Henrik David Bohr (1885–1962)	Atom model in which the electrons were presumed to occupy stable orbits demarcated by well-defined energy levels. This theory underwrites the quantum aspect of the absorption and emission of light by an atom resulting from the acceleration of an electron moving from one orbit to another orbit of different energy. This also provides an explanation of the absorption and emission at particular frequencies that are characteristic for that particular atomic energy configuration, depending on the element in question. Niels Bohr was awarded the Nobel Prize in Physics in 1922.
1913	Johannes Stark (1874–1957)	Observation of the splitting of spectral lines radiated by excited atoms in an applied intense external electric field: Stark effect. Johannes Stark received the Nobel Prize in Physics in 1919.
1913	James Franck (1882–1964) and Gustav Hertz (1887–1975)	Provided experimental evidence supporting the Bohr atomic theory pertaining to ionization and resonance potentials. Both James Franck and Gustav Hertz were awarded the Nobel Prize in Physics in 1925.
1913	William Henry Bragg (1862–1942) and William Lawrence Bragg (1890–1971)	Studied X-ray “reflection” (scatter) from crystals (Bragg law) and devised an X-ray spectrometer. They were awarded the Nobel Prize in Physics in 1915.
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1913	Frederick Soddy (1877–1956)	Formal introduction of the isotope concept.
1914	Niels Henrik David Bohr (1885–1962)	Description of the atomic energy layer model; hydrogen (Bohr atomic model).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1914	Henry Gwyn Jeffrey Moseley (1884–1915)	X-ray spectrograms of the elements which assisted in the establishment of the identity of the ordinal number of respective elements in the periodic table associated with its nuclear charge: atomic number.
1914	Karl Manne Georg Siegbahn (1886–1978)	Series of pioneering efforts in the theory and application of precision X-ray spectroscopy. Karl Siegbahn received the Nobel Prize in Physics in 1924.
1915	Sir Ernest Marsden (1889–1970)	Artificial transmutation, associated with the element radon enclosed by vacuum.
1915	Arnold Johannes Wilhelm Sommerfeld (1868–1951)	Improvements to the Bohr atomic model by introducing elliptical orbits and relativistic effects.
1915	William Duane (1872–1935) and Franklin Livingston Hunt (1883–1973)	Computational proof that the short-wavelength limit of emitted radiation is determined by the quantum theory.
1915	Albert Einstein (1879–1955)	Introduction of the general theory of relativity, describing the conditions that apply to the observations of phenomena on accelerated reference frames.
1916	Robert Andrews Millikan (1868–1953)	Experimental verification of Einstein's photoelectric equation.
1916	Peter Joseph Wilhelm Debye (1884–1966), Paul Scherrer (1890–1969), next to Albert Wallace Hull (1880–1966)	Obtained the first experimental x-ray powder diffraction patterns.
1916	Theodore Lyman (1874–1954)	Atomic absorption\emission series for hydrogen providing the Lyman series lines predicted by the Niels Henrik David Bohr (1885–1962) theory of the hydrogen atom. Theodore Lyman had documented observing at least one of these lines as early as 1906.
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. Nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.
1919	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Artificial transmutation, hydrogen formation resulting from collisions of alpha particles with nitrogen, also generating oxygen and gamma rays.
1919	Ernest Rutherford (Lord Rutherford of Nelson, 1st Baron) (1871–1937)	Alpha particle bombardment of nitrogen producing hydrogen and oxygen, the first “man-made” transmutation of an element.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1919	Francis William Aston (1877–1945)	First high-precision determination series measurements of isotopic masses. Francis Aston received the Nobel prize in Chemistry in 1922.
1921	James Chadwick (1891–1974) and Étienne Samuel Biéler (1895–1929)	Strong nuclear force.
1921	Otto Stern (1888–1969) and Walter Gerlach (1889–1979)	Verification of the space quantization for silver atoms exposed to a magnetic field while measuring their magnetic moment. Otto Stern received the Nobel Prize in Physics in 1943.
1923	Arthur Holly Compton (1892–1962)	Discovery of the Compton effect, verifying that a photon has momentum. Arthur Holly Compton received the Nobel Prize in Physics jointly with Charles Thomson Rees Wilson (1869–1959) in 1927.
1923	Arthur Holly Compton (1892–1962)	Description of the deflection of photons by a charge unit, generally an electron, potentially the nucleus: Compton effect
1924	Edward Victor Appleton (1892–1965), Arthur Edwin Kennelly (1861–1939) next to Oliver Heaviside (1850–1925)	Initiation of a series of experiments that established the existence and properties of ionized layers in the upper atmosphere. The existence of this type of layers had been postulated by Arthur Edwin Kennelly (1861–1939) in 1902 and, independently, by Oliver Heaviside (1850–1925) to explain the observed implications for long-distance wireless telegraphy. Edward Appleton received the Nobel Prize in Physics in 1947.
1924	Satyendra Nath Bose (India, 1894–1974) next to Albert Einstein (1879–1955)	Independent introduction of the statistical formulation “obeyed” by bosons; a collective name for photons, nuclei of even mass number, and specific other particles.
1925	Johannes Geiger (1822–1945) and Walther Wilhelm Georg Bothe (1891–1957)	Conservation of energy for atomic and nuclear processes.
1925	Werner Karl Heisenberg (1901–1976)	Uncertainty principle.
~1925	Friedrich Hermann Hund (1896–1997)	Recognition of the “Coulomb barrier” in nuclear collision, providing a “tunneling” effect for the release of alpha particles. Also recognized as “quantum tunneling.”
1924	Louis Victor Duc De Broglie (1892–1987)	Introduced the concept of de Broglie waves, the beginning of the wave theory of matter. Louis Victor, Duc De Broglie received the Nobel Prize in Physics in 1929.
1925	Walter M. Elsasser (1904–1991)	Predicted from de Broglie theory illustrating how electrons could be diffracted by crystals.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1925	Charles Drummond Ellis (1895–1980) and William A. Wooster (1903–1984)	Established that in a number of elements the emission of either an alpha or a beta particle precedes the radiation of gamma rays, and thus the latter should be associated with the daughter product, not with the parent.
1925	Pierre Victor Auger (1899–1993)	Discovery of a type of energy transition in which an electron in an atom transitions from a higher to a lower energy state by ejecting one of its own electrons, however, without the emission of electromagnetic radiation: Auger electron. This phenomenon was reported also by Lise Meitner (1878–1968) around the same time.
1925	George Eugene Uhlenbeck (1900–1988) and Samuel Abraham Goudsmit (1902–1978)	Introduction of spin and magnetic moment of the electron into atomic theory.
1925	Wolfgang Pauli (1900–1958)	Announced the exclusion principle. Wolfgang Pauli received the Nobel Prize in Physics in 1945.
1925	Patrick Maynard Stuart Blackett (1897–1974)	Obtained the first cloud chamber tracks of the induced transmutation of nitrogen and of other elements, and later made many cosmic ray studies. He was awarded the Nobel Prize in Physics in 1948.
1925	Max Born (1882–1970) and Werner Karl Heisenberg (1901–1976), and Pascual Jordan (1902–1980)	Development of quantum mechanics principles. Later, Born originated the statistical interpretation of wave mechanics. Max Born received the Nobel Prize in Physics jointly with Walther Wilhelm Georg Bothe (1891–1957) in 1954.
1926	Erwin Schrödinger (1887–1961)	Introduction of the wave mechanical theory for the hydrogen atom. Erwin Schrödinger was awarded the Nobel Prize in Physics and shared it with Paul Adrien Maurice Dirac (1902–1984) in 1933.
1926	Enrico Fermi (1901–1954) and Paul Adrien Maurice Dirac (1902–1984)	Independent introduction of the statistical formulation “obeyed” by fermions, a collective name for electrons, nuclei of odd mass number, some particles, and in particular the electron gas in a conductor. Both Enrico Fermi and Paul Adrien Maurice Dirac were awarded the Nobel Prize for work listed at a later time in this chronology.
1926	Eugene Paul Wigner (1902–1995)	Series publications on the application of group theory in quantum mechanics. Eugene Wigner shared the Nobel Prize in Physics jointly with Maria Goeppert-Mayer (Göppert) and Johannes Hans Daniel Jensen (1907–1973) in 1963.
1927	Werner Karl Heisenberg (1901–1976)	Announcement of the uncertainty principle; “Unbestimmtheit Prinzip.” Karl Heisenberg received the Nobel Prize in Physics in 1932.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1927	Clinton Joseph Davisson (1881–1958), Lester Halbert Germer (1896–1971), and George Paget Thomson (1892–1975)	Electron diffraction from single crystals, and additionally George Paget Thomson obtained powder electron diffraction patterns. This work validated the existence of de Broglie waves. Clinton Davisson and George Thomson shared the Nobel Prize in Physics in 1937.
1927	Werner Karl Heisenberg (1901–1976)	Quantum uncertainty principle.
1927	Paul Adrien Maurice Dirac (1902–1984)	Description of antimatter.
1928	Edward Uhler Condon (1902–1974) and Ronald Wilfrid Gurney (1898–1953) next to George Gamow (1904–1968)	Solution to the nuclear problem of alpha particle emission using wave mechanics and they derived the Geiger–Nuttall law, in reference to the work of Johannes Geiger (1822–1945) and John Mitchell Nuttall (1890–1958).
1928	Paul Adrien Maurice Dirac (1902–1984)	Introduction of relativistic quantum mechanics and prediction of the existence of the positron. Paul Dirac shared the Nobel Prize in Physics with Erwin Schrödinger (1887–1961) in 1933.
1928	Chandrasekhara Venkata Raman (1888–1970)	Description of the Raman effect. This is the presence of frequencies differing from that of the incident light resulting from scattered by molecules. The shifts in frequency are characteristic of the scattering substance (molecular energy information) and independent of the incident frequency. Chandrasekhara Raman received the Nobel Prize in Physics in 1930.
1928	Dmitri Vladimirovich Skobeltsyn (1892)	Construction of the first cloud chamber, producing photographs of cosmic rays. These photographs revealed that cosmic rays either were, or produced, many charged, high-energy particles.
1928	Hans Geiger (1882–1945) and Walther Müller (1905–1979)	Improved form of the 1913 Geiger counter, referred to as the Geiger–Müller counter.
1928	Walther Wilhelm Georg Franz Bothe (1891–1957) and Werner Heinrich Gustav Kolhörster (1887–1946)	Application of Geiger–Müller tubes to make coincidence counters and other innovative devices specifically designed for high sensitivity cosmic-radiation study. Walther Bothe shared the Nobel Prize in Physics with Max Born (1882–1970) in 1954.
1928	Johannes Geiger (1822–1945) and Walther Müller (1905–1979)	Introduction of an improved Geiger counter: the Geiger–Müller counter, using ionization of a confined gas.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1929	Leo Szilard (1898–1964) and Ernest Orlando Lawrence (1901–1958)	Particle accelerator: cyclotron. The cyclotron can accelerate protons to reach kinetic energy in excess of 700 MeV, with respective radius of 4.6 meter (1946). The first cyclotron was built in 1932, at the University of California Berkeley, California: Tevatron. Cyclotrons are specifically not exclusively, used to create isotopes for use in nuclear medicine, in particular for imaging (e.g., PET) and for cancer treatment.
1929	Otto Stern (1888)	Obtained crystal diffraction of a beam of helium atoms.
1930	Fredrik Carl Muelertz Stoermer (1874–1957), Georges Lemaitre (1894–1966), and Manuel Sandoval Vallarta (1899–1977)	Applied the theory of the motion of charged particles in the earth's magnetic field, originally developed to account for the aurora borealis, to integrate cosmic rays. This theory of the cause of geomagnetic effects was greatly expanded in 1933 by Georges Lemaitre Manuel Sandoval Vallarta. Additional theoretical work was implemented by William Francis Gray Swann (1884–1962) and others.
1930–1933	Ira Forry Zartman (1899–1981)	Experimental verification of the Maxwell distribution law of molecular velocities; Maxwell–Boltzmann distribution.
1931	Thomas Hope Johnson (1899–1998)	Experimental crystal diffraction of a beam of hydrogen atoms.
1931	Robert Jemison Van De Graaff (1901–1967)	First reliable, high-voltage, electrostatic generator for nuclear research.
1931	Wolfgang Ernest Pauli (1900–1958)	Expressed the hypothesis of beta decay processes postulating that a “new,” small, neutral particle (the neutron) should be emitted concurrently with the electron. Energy when involved in beta decay up to 0.5 MeV. The experimental verification of the existence of the neutrino was not until 1956 by Frederick Reines (1918–1998) and Clyde Cowan Jr. (1919–1974).
1931	Carl David Anderson (1905–1991)	Discovery of the positron, anti-particle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929. Carl Anderson received the 1936 Nobel Prize in Physics for this discovery in 1936, and he also discovered the muon in 1936.
1931	Harold Clayton Urey (1893–1981), Ferdinand Graft Brickwedde (1903–1989), and George Moseley Murphy (1905–1968)	Discovery of deuterium and composition of the first “heavy water.” Harold Urey received the Nobel Prize for Chemistry in 1934.
1931	Carl David Anderson (1905–1991)	Discovery of the positron, anti-particle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1932	Sir James Chadwick (1891–1974)	Discovery of the neutron. Student of Ernest Rutherford (1871–1937).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1932	Ernest Orlando Lawrence (1901–1958) and Milton Stanley Livingston (1905–1986)	Construction of the first cyclotron. Ernest Lawrence was awarded the Nobel Prize in Physics in 1939.
1932	Sir John Douglas Cockcroft (1897–1967) and Ernest Thomas Sinton Walton (1903–1995)	Facilitated the transmutation of lithium by impaling by high-energy protons, and hence provided the first direct verification of the Einstein law for mass–energy equivalence. This experiment denotes the first time a high-voltage accelerator was successfully used to produce a nuclear reaction. Sir John Cockcroft and Ernest Walton shared Nobel Prize in Physics in 1951 for their work.
1932	James Chadwick (1891–1974)	Discovery of the neutron. This particle accounted for the penetrating “radiation” described by Walther Wilhelm Georg Bothe (1891–1957) and Herbert Becker (?). James Chadwick was awarded the Nobel Prize in Physics in 1935.
1932	Bruno Benedetto Rossi (1905–1993)	Realization that there is an initial increase in radiance under “transmittance” through an absorbing layer. Bruno Rossi associated this with cosmic ray showers. A transition to decreasing radiance was achieved when the layer thickness exceeded a certain value.
1932	Carl David Anderson (1905–1991)	Discovery of the positron during cosmic ray research. Carl David Anderson shared the Nobel Prize in Physics with Victor Francis Hess (1883–1964) in 1936.
1933	Patrick M. S. Blackett (1897–1974) and Giuseppe P. S. Occhialini (1907–1993)	Electron–positron pair production under cloud chamber observation; first cloud chamber photographs.
1933	Jean Valentin Thibaud (1901–1960) and Frederic Joliot (1900–1958)	Detection of radiation produced by electron-positron annihilation. Jean Thibaud and Frederic Joliot also showed the equivalence of the mass of the positron to that of the electron.
1933	Thomas Hope Johnson (1899–1998) and Jabez Curry Street (1906–1989)	Observation that the cosmic ray radiance from the west is greater than what is emerging from the east. This east–west asymmetry illustrates the excess of positively charged particles in the primary cosmic ray trajectory coming in from outer space, with a significant contribution from the Sun.
1934	Pavel Alekseyevich Cherenkov (1904–1990) [Russian: Пáвeл Алeксéевич Чeрeнкóв], Igor Yevgenyevich Tamm (1895–1971) [Russian: Игoрь Евгéньевич Тaмм], and Ilya Mihajlovic Frank (1908–1990) [Russian: Илья Михайлович Фpaнк]	Pavel Cherenkov observed a weak, bluish glow in transparent media when irradiated by high-energy beta particles. The theoretical explanation for this Cherenkov radiation was given by Ilya Mihajlovic Frank and Igor Yevgenyevich Tamm three years later. These three scientists shared the Nobel Prize in Physics in 1958.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1934	Stjepan Mohorovičić (1890–1980)	Prediction of a transitory non-nuclear “element”; later named positronium. This formation precedes electron–positron annihilation.
1934	Irene Joliot-Curie (1897–1956) and Frederic Joliot (1900–1958)	Discovery of artificial radioactivity. Irene Joliot-Curie and Frederic Joliot shared the Nobel prize in chemistry in 1935.
1934	Enrico Fermi (1901–1954), Edoardo Amaldi (1908–1989), Oscar D’Agostino (1901–1975), Franco Dino Rasetti (1901–2001), and Emilio Gino Segre (1905–1989)	Enrico Fermi developed Pauli’s theory of beta decay and named the “new” particle the neutrino (little neutron). It is postulated in Fermi’s theory that the neutron is radioactive, disintegrating into a proton with the formation of an electron and a neutrino just before beta emission. Fermi also began a series of experiments in collaboration to produce transuranic elements by irradiating uranium with neutrons. They were granted a patent on the graphite moderator in 1955. Fermi was awarded the Nobel Prize in Physics in 1938.
1934	Leo Szilard (1898–1964)	Recognition of nuclear decay chain reactions.
1934	Hideki Yukawa [湯川 秀樹], (1907–1981)	Introduction of mesons and the initial concept of anti-matter. In 1935 Hideki Yukawa postulation of his theory of nuclear binding resulting from a particle that has a mass that lies between that for an electron and a proton. Hideki Yukawa received the Nobel Prize in Physics for this work in 1949.
1934	Ida Noddack (1896–1978)	Formal introduction of the concept of “fission,” however not recognized by her peers at the time. The fission phenomenon was only recognized when announced by Enrico Fermi (1901–1954) later that year.
1934	Enrico Fermi (1901–1954)	Interaction of slow neutron with nuclei and the resulting decay into different elements, including aluminum and uranium
1935	Arthur Dempster (1886–1950)	Discovery of the lighter uranium isotope: uranium-235
1935–1939	Isidor Isaac Rabi (1898–1988)	Precise determination of the nuclear magnetic moment within rays of atoms using an experimental set-up constructed with his radio frequency resonance method. Isidor Isaac Rabi received the Nobel Prize in Physics in 1944.
1936	Carl David Anderson (1905–1991) and Seth Henry Neddermeyer (1907–1988)	Discovery of a particle of the type postulated by Yukawa, observed during cosmic ray research The new particle was called “mesotron,” later renamed as “meson.”
1936	Marietta Blau (1894–1970)	First experimentalist to systematically make use of nuclear track plates.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1936	Otto Hahn (1879–1968) and Lise Meitner (1878–1968)	Neutron collision of uranium-induced decay examination.
1937	Carl David Anderson (1905–1991), Seth Henry Neddermeyer (1907–1988), Jabez Curry Street (1906–1989), and Edward C. Stevenson (20th century)	Confirmation of the existence of the meson and muon. Subatomic particles are governed by quantum physics principles, and will exhibit a wave–particle duality. The quantum state energy vectors are represented in Hilbert space.
1937	Niels Henrik David Bohr (1885–1962)	Introduction of the liquid drop model or the atomic nucleus.
1938	Irene Joliot-Curie (1897–1956) and Pavle Savic/Savitch (1903–1994)	Discovery of lanthanum in uranium after irradiation by neutrons.
1938	Otto Hahn (1879–1968) and Fritz Strassmann (1902–1980)	Bombarding uranium with neutrons produces alkali earth elements. Otto Hahn received the Nobel Prize in Chemistry in 1944.
1938	Niels Henrik David Bohr (1885–1962) and John Archibald Wheeler (1911–2008)	Formal description of the nuclear fission process.
1939	Jerome M. B. Kellogg (1905)	Discovery of a finite quadruple moment for the deuteron, requiring a non-central (tensor) nuclear force configuration.
1939	Lise Meitner (1878–1968) and Otto Robert Frisch (1904–1979)	Nuclear splitting in an attempt to explain the result from Otto Hahn (1879–1968) on the disintegration of uranium by neutron impact. They predicted the release of a substantial amount of energy resulting from fission.
1939	Niels Henrik David Bohr (1885–1962) and John Archibald Wheeler (1911–2008)	Introduction of theory of nuclear fission.
1939	Hans Albrecht Bethe (1906–2005) next to Carl Friedrich Von Weizsäcker (1912–2007)	Two groups that independently proposed two equivalent sets of nuclear reactions to account for stellar energies: the proton–proton chain and the carbon cycle.
1940	John Ray Dunning (1907–1975), Eugene Theodore Booth (1912–2004) and Aristid V. Grosse (1905–1980)	Experimental observation of the fission of U235, the less abundant isotope of uranium, by means of slow neutrons.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1940	Louis Leprince-Ringuet (1901–2000)	Obtained the first cloud chamber photograph of a collision between a meson and an electron, from which the mass of the meson could be derived.
1940	Donald William Kerst (1911–1993)	Construction of the first betatron, an induction type accelerator.
1940	Edwin Mattison McMillan (1907–1999), Philip Hague Abelson (1913–2004), Glenn Theodore Seaborg (1912–1999), Joseph William Kennedy (1916–1957), and Arthur Charles Wahl (1917–2006)	Production of the first transuranic element, neptunium. Additional work included the second transuranic element, plutonium. Edwin McMillan and Glenn Seaborg shared the Nobel Prize in Chemistry in 1951.
1940	Otto Robert Frisch (1904–1979)	Development of the detonation mechanism for the first atomic bomb.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more.
1942	Enrico Fermi (1901–1954) and Leo Szilard (1898–1964)	Design and construction of the first successful self-sustaining fission reactor, located in Chicago, Illinois. The reactor was first placed in operation on December 2 and produced a power level of one-half watt.
1945	J. Robert Oppenheimer (1904–1967)	Director of the Los Alamos Scientific Laboratory, managing a large select group of scientists engaged in a program of basic nuclear research and development. The culmination of this work was the detonation of the first nuclear bomb at Alamogordo, New Mexico, on July 16, 1945.
1945	Edwin Mattison McMillan (1907–1999) next to Vladimir Iosifovich Veksler (1907–1966)	Independent introduction of the principle of the synchrotron. The synchrotron accelerator produces very high-energy particles, as in the Cosmotron, Brookhaven National Laboratory, Upton, New York, operating at 3.3 GeV and revealed mesons generally only generated under cosmic ray interaction; or Bevatron, Lawrence Berkeley National Laboratory, Berkeley, California, operating a proton beam at 10 BeV.
1946	Felix Bloch (1905–1983) and Edward Mills Purcell (1912–1997)	Designed the magnetic induction method. Independently, both groups developed the magnetic resonance absorption method for the determination of nuclear magnetic moments, using both liquids or solids. Their work led to the nuclear resonance spectrometer. Felix Bloch and Edward Purcell received the Nobel Prize in Physics in 1952.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1946		Introduction of the term “Lepton,” defining weak nuclear interaction particles; electrons and muons are hence considered leptons.
1947	George Dixon Rochester (1908–2001) and Clifford Charles Butler (1922–1999)	Discovery of the subatomic particle: the “kaon,” k-meson. Introduction of the “strangeness” concept for quarks, although the quark concept had not been introduced. In the elementary particle phenomenology the kaon is a bound state of an up- or down quark with a strange quark (anti-quark).
1947	Maria Goeppert-Mayer (Göppert) (1906–1972)	Theoretical concept development for the understanding of nuclear forces, based on a shell model, similar to the atomic electron model.
1947	William Webster Hansen (1909–1949)	Linear accelerator installation at Stanford University, California.
1947	Polykarp Kusch (1911–1993)	High precision assessment of the magnetic moment for the electron. Polykarp Kusch discovered a small but theoretically significant difference between the predicted value of the moment and the experimental results. Polykarp Kusch shared the Nobel Prize in Physics with Willis Eugene Lamb (1913–2008) in 1955.
1947	Willis Eugene Lamb, Jr., (1913–2008) and Robert E. Retherford (1882–1939)	Description of the Lamb shift, observed during the course of spectral measurements of the fine structure of hydrogen in the microwave region. This small displacement of an energy level from its theoretical position was predicted by Dirac’s quantum theory of the electron (Paul Adrien Maurice Dirac [1902–1984]). Willis Lamb was awarded the Nobel Prize in Physics jointly with Polykarp Kusch (1911–1993) in 1955.
1947	Hans Albrecht Bethe (1906–) next to Julian Seymour Schwinger (1918–1994)	Explanation of the discrepancies published by Willis Eugene Lamb (1913–2008) and Polykarp Kusch (1911–1993) resulting from an interaction of electrons with an applied radiation field. Julia Schwinger shared the Nobel Prize in Physics with Richard Phillips Feynman (1918–1988) and Sin-Itiro Tomonaga [朝永 振一郎] (1906–1979) in 1965.
1947	Hartmut Paul Kallmann (1896–1978), next to John Wesley Coltman (1915–2010) next to Fitzhugh Ball Marshall (1912–1965)	Development of scintillation counters.
1947	Cecil Frank Powell (1903–1969), Giuseppe P. S. Occhialini (1907–1993), and Cesare Mansueto Giulio Lattes (1924–2005)	Discovery of the pi-meson. Cecil Powell received the Nobel Prize in Physics in 1950.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1947	George Dixon Rochester (1908–2001) and Clifford Charles Butler (1922–1999)	Discovery of V-particles and hyperons.
1948	Eugene Gardner (1913–1950) and Césaire Mansueto Giulio Lattes (1924–2005)	First artificial production of mesons in the laboratory.
1948–1950	Willard Frank Libby (1908–1980) and James Richard Arnold (1923–2012)	Development of radiocarbon dating with his group at the University of Chicago, Institute for Nuclear Studies (now Enrico Fermi Institute for Nuclear Studies). Carbon dating has a time range limit of approximately 50,000 years. Frank Libby received the Nobel Prize in Chemistry in 1960.
1949	Maria Goeppert-Mayer (Göppert) (1906–1972) next to Otto Haxel (1909–1998), Johannes Hans Daniel Jensen (1907–1973) and Hans Edward Suess (1909–1993)	Introduction of the shell theory of the nucleus, which assumes a spherical organization of nucleons, similar to that for the electrons. Maria Goeppert-Mayer (Göppert) and Johannes Jensen shared the Nobel Prize in Physics with Eugene Paul Wigner (1902–1995) in 1963.
1950	Arthur Hawley Snell (1909–1989) and John Michael Robson (1920–2000)	While at the Oak Ridge National Laboratory, in collaboration with the Chalk River Laboratory provided the experimental verified that the free neutron is radioactive.
1950		Scientists began intensified research on light-element fusion reactions.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model for atomic nuclei.
1951	Martin Deutsch (1917–2002)	Experimental confirmation of the prediction of the existence of positronium.
ca. 1952	Ludwig von Helmholtz (1821–1894), Lyman Strong Spitzer, Jr (1914–1997) and Ronald Richter (1909–1991) and Edward Teller (1908–2003)	Nuclear fusion investigation and start of experimentation. The process was in principle described by Hermann Ludwig Ferdinand von Helmholtz (1821–1894), but is continuously in action at the Sun's surface.
1952		Brookhaven National Laboratory was the first accelerator to achieve the acceleration of proton particles to the giga-electron-volt energy range: 2.3-GeV.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1952	Aage Niels Bohr (1922–2009), Benjamin Roy Mottelson (1926–) and Leo James Rainwater (1917–1986)	Unified (collective) shell model of the nucleus. This shell model assumes a nonspherical nuclear core. The possibility of a distorted core had been suggested in 1950 by Ben Mottelson (1926–) and James Rainwater, for which they shared the Nobel Prize in Physics in 1975, along with Aage Bohr for their contributions to the description of the nonspherical geometry of atomic nuclei.
1952	Donald Arthur Glaser (1926–2013)	Construction of the first bubble chamber. Donald Glaser received the Nobel Prize in Physics in 1960. This first large-scale, terrestrial thermonuclear reaction was produced when a “hydrogen fusion device” was being tested on the Einewetok atoll, Marshall islands, on November 1.
1953	Murray Gell-Mann (1929–)	Introduction of the strangeness “numbers” for nucleons, mesons, and hyperons. Gell-Mann recognized that strangeness is conserved when part of strong interactions.
1953	Robert Hofstadter (1915–1990)	Experimental observation of the scattering of high-energy electrons by atomic nuclei and atoms. The results obtained led to the determination of the charge distribution and structure of nuclei and nucleons. Hofstadter was awarded the Nobel Prize in Physics jointly with Rudolph Ludwig Mössbauer (1929–2011) in 1961.
1954	James Power Gordon (1928–2013), Herbert J. Zeiger (1925–2011), and Charles Hard Townes (1915–2015)	Construction of the first maser (molecular [formerly, microwave] amplification by stimulated emission of radiation). In this device configuration, many molecules can simultaneously be placed into high energy states and are subsequently induced to emit their energy as radiation under stimulation from a weak incoming signal of the same frequency. Charles Hard Townes shared the Nobel Prize in Physics with Nikolay Gennadiyevich Basov [Russian: Никола́й Генна́диевич Ба́сов] (1922–2001) and Alexander Mikhaylovich Prokhorov, [Russian: Алекса́ндр Миха́йлович Про́хоров] (1916–2002) in 1964.
1954	Chen-Ning Franklin Yang (1922–2004) and Robert Laurence Mills (1927–1999)	Introduction of “gauge theories.” These gauge theories will eventually form the basis for the “standard model.”
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1955	Owen Chamberlain (1920–2006), Emilio Gino Segre (1905–1989), Clyde Edward Wiegand (1915–1996), and Thomas John Ypsilantis (1928–2000)	Creation of proton–antiproton pairs. Owen Chamberlain and Emilio Segre were awarded the Nobel Prize in Physics in 1959.
1956	Luis Walter Alvarez (1911–1988)	Cold fusion of deuterium using the negative mu-meson as a catalyst.
1956	John Bardeen (1908–1991), Walter Houser Brattain (1902–1987), and William Shockley (1910–1989)	These scientists shared the Nobel Prize in Physics in recognition of their work in the theoretical description of the solid state, in particular the semiconductor medium.
1956	Frederic Reines (1918–1998) and Clyde Lorrain Cowan, Jr. (1919–1974)	Experimental confirmation of the existence of the neutrino. Frederic Reines and Martin Lewis Perl (1927–2014) shared the Nobel Prize in Physics in 1995; since Clyde Lorrain Cowan, Jr. had passed away in 1974 he was not included since the Nobel Prize is awarded posthumously.
1956	Frederick Reines (1918–1998) and Clyde Cowan Jr. (1919–1974)	The experimental verification of the existence of the neutrino based on the 1931 work by Wolfgang Ernest Pauli (1900–1958).
1956		The world's first full-scale nuclear power plant was put into operation on October 17 at Calder Hall, England. The gas-cooled reactors develop 360 megawatts of thermal power to deliver 78 megawatts of electrical power.
1956	Tsung Dao Lee (1926–) and Chen Ning Yang (1922–)	Theoretical explanation that the law of conservation of parity, representing the invariance of spatial inversion, is invalid for weak interactions. They shared the Nobel Prize in Physics in 1957.
1956	Frederick Reines (1918–1998) and Clyde Lorrain Cowan Jr. (1919–1974)	Experimental confirmation of the neutrino introduced in 1931 by Wolfgang Pauli (1900–1958)
1956	Chien-Shiung Wu (1912–1997)	First experiment that exposed the violation of conservation of parity. Chien-Shiung Wu observed the beta emission from cobalt-60 (Co-60) at very low temperatures.
1957	Julian Schwinger (1918–1994), Sidney Bludman (1927–), Sheldon Lee Glashow (1933–), and Hideki Yukawa (1907–1981)	Bosons provide the weak attraction. Initially conceived by Hideki Yukawa (1907–1981) in 1937. These heavy bosons are referred to as W^- and W^+ .

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1957	John Bardeen (1908–1991), Leon N. Cooper (1930–) and John Robert Schrieffer (1931–)	First comprehensive theory of superconductivity. They all shared the Nobel Prize in Physics in 1972.
1958	Stanley Mandelstam (1928–)	Introduction of Mandelstam variables associated with the concept of “crossing symmetry,” defining numerical quantities which encode the energy, momentum, and scattering angles of particles in a deflection process described in a Lorentz invariant fashion
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович (Бенедиктович) Мигдал] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.
1958	Charles Hard Townes (1915–), John Perry Cedarholm (1927–), George Francis Bland (1927–2010), and Byron Luther Havens (1914–1989)	Experimental application of maser beams constructing the most precise ether-drift experiment yet. The results tentatively eluded to the fact that if the effect exists, it is less than one-thousandth of the earth’s orbital speed or less than one ten-millionth of the speed of light. The precision in the frequency comparison of the masers was about one part in a 10^{12} .
1958	Rudolph Ludwig Mössbauer (1929–2011)	Predicted and experimentally verified an extremely small frequency spread in the low-energy gamma emission from nuclei bound in a crystal lattice. This effect results from transferring the gamma ray recoil momentum to the whole lattice instead of to an individual nucleus. The Mössbauer effect provides a very high precision frequency standard which lends itself for verification of several predictions made with regard to the special and general theories of relativity. Rudolph Mossbauer shared the Nobel Prize in Physics jointly with Robert Hofstadter (1915–1990) in 1961.
1959	James Alfred Van Allen (1914–2006)	Obtained data from instruments hosted on artificial satellites and derived that the earth is encircled by two zones, referred to as “Van Allen” (radiation) belts. The Van Allen belts consist of high-energy charged particles that are harnessed by the earth’s magnetic field.
1960	Vernon Willard Hughes (1921–2003), Douglas W. McColm (1933?–), Klaus Otto Heinrich Ziock (1925–2010) and Richard Prepost (?–?)	Constructed and studied the atom muonium, a short-lived atom with a positive mu-meson as nucleus and a single orbiting electron.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1961	Murray Gell-Mann (1929–)	Description of elementary particles, eight-fold way of defining “strangeness” for the quark. Formal introduction of the elementary particle “quark” concept, the building blocks for protons and neutrons. The “quark” name is based on an expression in the book <i>Finnegans Wake</i> by James Joyce.
1962	Brian David Josephson (1940–)	Discovery and theoretically analyzation of a number of unexpected phenomena occurring at a “Josephson junction.” The Josephson junction represents an arrangement consisting of two superconductors that are separated by a very narrow layer of insulating material.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Никола́й Генна́диевич Ба́сов] (1922–2001) and Aleksandr Mikhailovich Prokhorov [Алекса́ндр Миха́йлович Про́хоров] (1916–2002)	Quantum electronics.
1965	Oscar Wallace Greenberg (1932–), Moo-Young Han (1934–), and Yoichiro Nambu [南部陽一郎] (1921–)	Introduction of the concept of “color” change as designation and property for quarks.
1965	George Claude Pimentel (1922–1989) and Jerome V. V. Kasper (??)	Construction of first chemical laser, laser action relying on pumping energy supported by chemical reactions, in contrast to an external source of power, generally irradiation.
1970	Sheldon Lee Glashow (1932–), John Iliopoulos (1940–), and Luciano Maiani (1941–)	Introduction of the charm quark.
1973	Hugh David Politzer (1949–), David Jonathan Gross (1941–), and Frank Anthony Wilczek (1951–2015)	Discovery associating the quark color theory of the strong interaction to a special property, referred to as “asymptotic freedom.” This “color” property is required to describe the data acquired over the prior period from 1968 to 1969 with respect to the substrate of the proton.
1974	Burton Richter (1931–) and Samuel Chao Chung Ting [Chinese: 丁肇中] (1936–)	Description of charm for the quark.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1975	Carlo Rubbia (1934–), Burton Richter (1931), Frederick Reines (1918–1998), Jack Steinberger (1921), Leon Lederman (1922–), Richard Taylor (1929–), Jerome Friedman (1930), and Martin Perl (1927–2014)	Standard model of particle interaction. Interactions between leptons and quarks, interacting by means of bosons. Listing the contributing scientist that led to the discovery of the various elementary particles, respectively: W and Z boson; charm quark; neutrino; muon–neutrino; muon–neutrino and b-quark; quarks (general); quarks (general); tau.
1975	Martin Lewis Perl (1927–2014)	Discovery of the tau lepton.
1977	Leon Max Ledderman (1922–)	Discovery of the “beauty” and “bottom” designation for quarks.
1978		Discovery of the “gluon” with the assistance of the PLUTO, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1983	Collider Detector at Fermilab	World’s first and at the time highest-energy particle accelerator, colliding antiprotons, and protons propelled to center-of-mass energy reaching 2 TeV.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland. The Large Hadron Collider construction started in 1998 and produces particle acceleration with respective energy levels for protons at up to 4 teraelectronvolts (0.64 microjoules), or lead nuclei: 2.76 TeV per nucleon or 574 TeV per nucleus. The proton energy level was increased to 6.5 TeV in 2015.

Biomedical

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
2900 BC		Construction of artificial eyes by Egyptian priest, without any optical function. These eyes were for “decoration” only, called Ectblepharons, worn generally outside the eye socket made from painted clay or enameled metal.
3000–2500 BC	Imhotep (c. 2650–2600 BC)	Papyrus scrolls describing several traumas and additional surgical procedures, in addition to the medical diagnosis and procedures related to pregnancy. The biomedical relevance primarily relates to the mechanical nature. Some aspects of the description of embalming for mummification and the removal of the brain through the nose are still relevant with respect to performing brain surgery, also through the nose if possible. But no reference to the functional aspects of the brain are made. Cancer was recognized and described.
1600 BC		Documented anatomical drawings found in Egypt displaying a rudimentary physiological and fluid dynamics as well as electrophysiological purpose of the following items hypothalamus, liver, kidneys, spleen, uterus, and bladder were documented. For the heart, with adjoining vessels, it was obvious that they were recognized to emanate from the heart. The papyrus scrolls also describe several identified ailments and diseases next to fractures and means to mend these afflictions.
ca. 400 BC	Plato, also known as Aristotle (427–347 BC)	Early misconceptions regarding vision. Object supposedly emit “light” which in turn is captured by the eye.
ca. 350 BC	Aristotle (384–322 BC)	Proposed the concept of light emitted by a source, such as a candle or the Sun, which is subsequently reflected by objects and hence captured by the eye; providing the fundamental principle of sight.
ca. 300 BC	Euclid of Alexandria (ca. 350 BC–280 BC)	Publication of the treatise on light: “optics” (Ὀπτικά), describing the principles of the image formation, next to general vision aspects related to the eye.
ca. 170	Claudius Galenus (130–201)	Detailed description of the anatomy of the eye: lens, retina, and optic nerve; however, still supporting the “extramission” concept introduced by Plato.
ca. 200	Claudius Galenus (130–201)	Initial measurements of the lung volume. Galen also introduced early concept of ventilation.
800s	Yaqub ibn Ishaq al-Kindi (801–873) and Abu Zayd Hunayn ibn Ishaq al-Ibadi (808–873)	Reiteration of the erroneous concept of extramission for sight

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~900	Mohammad ibn Zakariya al-Razi (864–930)	Realization of the fact that the diameter of the pupil of the eye responds to the magnitude of light finally revised the vision concept to that initially introduced by Aristotle using the external light sources as a means to support vision.
ca. 1000	Avicenna (980–1037)	Description of the power of locomotion with respect to the torque applied on joints resulting from muscular contraction. He also provided a rudimentary description of the pump function for the heart.
~1300	Henri de Mondeville (1260–1320)	Treatment attempt for smallpox using light.
1480	Leonardo da Vinci (1452–1519)	Leonardo da Vinci initially supported the erroneous extramission concept for vision, but finally rejected this based on his experimentation with image formation using an ox eye from which he had scraped the retina, providing a lens with “screen” that forms an image. Leonardo da Vinci also contributed significantly to the pictorial record keeping of muscle structures, types, and contraction mechanisms.
~1500		In-socket artificial eye development, still without a true optical function.
1535	Andrés de Laguna (1499–1559)	Detailed anatomical description with terminology describing the heart, consisting of two ventricles (announcing the “right” and “left” ventricle, as we currently know and use it) and two “auricles” as he referred to the atria.
1503	Gregor Reisch (1467–1525)	Detailed human anatomical drawings in the publication: <i>Margarita Philosophica</i> . The total works of Gregor Reisch form a series of 12 books compiling an encyclopedia describing topics ranging from Latin grammar, to dialectics, rhetoric, arithmetic, music, geometry, astronomy, physics, natural history, physiology, psychology, and ethics
1543	Andreas Vesalius (1514–1564)	Detailed description and graphic representation of the anatomy of the human body, circulation system, and rudimentary description of the function of several organs and their respective engineering and physics applications. Founder of the principles of modern anatomy.
1621	Willebrord Snell (1591–1626) and René Descartes (1596–1650)	Fundamental theoretical description supporting the concept of image formation by the lens of the eye based on the law of refraction.
1628	William Harvey (1578–1657)	Detailed functional description of the cardiovascular circulation, left heart for whole body and right heart to lungs. Referring to the observations and descriptions by Andrés de Laguna (1499–1559) a century prior.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1629	Réne Descartes (1596–1650)	Description of muscles, tendons, and some reference to external stimulation, as what we now know are nerve impulses. Confirming/underwriting the pump function of the heart muscle (cardiac muscle).
1653	William Harvey (1578–1657)	Detailed description of the actin and myosin fibers defining muscle contraction.
1681	Giovanni Alfonso Borelli (1608–1679)	Measurement of vital capacity and other volumetric data regarding respiration.
1750	Robert Whytt (1714–1766)	Description of the electrical stimulation of the “optic nerve” resulting from light reaching the retina. Although the nerve as a functional unit was not understood yet. The observations were primarily derived from follow-up responses (e.g., muscle contraction) produced by the individual in the experimental set-up.
	Emanuel Swedenborg (1688–1772)	Realization that the brain is the central processing unit for nerve impulses and motor control. Published posthumously. Unfortunately, his efforts were not recognized until the year 1887.
1776	Luigi Galvani (1737–1789)	Biomedical connection to electricity and development of a mechanism to measure electrical energy
1781	Felice Gaspar Ferdinand Fontana (1730–1805)	Description of the functional aspects of the nerve fiber, but not including the phenomenological description. The description was based on the elaboration of the “electric fish” (eel) by John Walsh (1725–1795) and the work of electrical interactions with the human body by Luigi Galvani (1737–1798). The electricity of the eel was known for millennia, but not understood.
1812	Julien Jean César Legallois (1770–1814)	Recognition of the part of the brain regulation respiration (medulla). Also described the fact that gas exchanges between blood and the cells changes the partial pressure of elements in the blood with respect to the surrounding tissues, the supply of oxygen to support the metabolism and the secretion of waste carbon dioxide. His ideas also introduced the use of external supply of arterial blood to extend life, but this was not implemented until much later.
1841	Claude Bernard (1813–1878)	Recognition of the chemical equilibrium supporting life and functionality of the cell (homeostasis).
1824	Félix Savart (1791–1841)	Description of the motion of the Tympanic membrane inside the inner ear (cochlea) under the influence of applied sound.
1826	Johannes Peter Müller (1801–1858)	Description of nerve impulses, and that a nerve will produce only one particular sensation, irrespective of the stimulus. This ties to the fact that the brain interprets the stimulus, which was not known at that time in detail.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~1844	Ludwig Feuerbach (1804–1872)	Description of the five individual senses: sight/vision, hearing, touch, taste, and smell, in addition to more derived sensations such as thought, love, and experience.
1849	John Hutchinson (1811–1861)	Description of the mechanism of tidal breathing relating the pressure in the lung (alveoli) to the volume of the different stages of respiration. This work relates directly to the theoretical description by Pierre-Simon Laplace (1749–1827).
1849	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Description of electrical stimulation resulting in muscle contraction. The decryption included a rudimentary reference to the concept of the action potential, which was at the time not known.
1855	Adolf Eugen Fick (1829–1901)	Fick's diffusion equation for gases and dissolved chemical constituents with respect to membranes.
1857	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Theoretical description of hearing based on the (misplaced) assumptions of the basilar membrane within the cochlea acting as a resonating structure. In this resonance cavity model the low-frequency tones activating the membrane from the apical turn and high-frequency tones activating it from the basal turn. This was later corrected by the work of Georg von Békésy (1899–1972). There are also indications placing these statement at an earlier date (other contributing persons, for instance his teacher: Johannes Müller [1801–1858]).
~1860		Replacement lenses to facilitate artificial eyes reconstruction is making a functional introduction. Small ocular lenses were blown with relatively high-quality glass, initiated in Germany.
1864	Adam Politzer (1835–1920)	Description of the movement of the ossicles in the middle ear under the influence of sound. This was another step into the understanding of the auditory functioning.
1864	Wilhelm Kühne (1837–1900)	Defined the term “myosin” as a molecular component in the contractile mechanism of action for muscle. Not by long a full description of the functional aspect for the muscle since the remaining components were not discovered until 1942 and later.
1868	Julius Bernstein (1839–1917)	Introduction to the formal mechanism of action for the action potential.
1870	Adolf Eugen Fick (1829–1901)	First recorded measurement of cardiac output; using the Fick principle.
1875	Richard Caton (1842–1926) [Lord Mayor of Liverpool]	Recognized electrical activity of the brain; initial indication for the recording of the electro encephalogram (EEG). Richard Caton contributed to the general understanding of the electrophysiology concepts.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~1890	Niels Ryberg Finsen (1860–1904)	Successful treatment of smallpox with light, building on the early work of Henri de Mondeville (1260–1320).
1888–1889	Walter Nernst (1864–1941)	Definition of the electrochemical potential across a cellular membrane due to the gradient in chemical concentration for several elements. This process produces a “half-cell potential,” similar to what is found in batteries. This can be placed in perspective to the first “battery” that is practical in use, designed by Alessandro Giuseppe Antonio Anastasio Volta (1745–1827) in 1800.
~1900	Oscar Raab (1876?–1986) and Giorgio Marcacci (18??–19??)	Discovery of the phototoxicity of light, specifically in the eradication of cancer.
1901	Willem Einthoven (1860–1927)	Invention of the first user friendly and reproducible electrocardiogram recorder (ECG, also found as EKG) pertaining to the electrical excitation for the contractility of the respective (cardiac-) muscle compartments of the hearts. Willem Einthoven used sting galvanometers of his own design. This provided an essential contribution to the understanding of cardiac arrhythmias and heart problems including the resulting fluid-dynamic results from the whole cardiovascular system.
1905	Nikolai Korotkoff (1874–1920)	Discovery of the sounds produced by arterial blood flowing through the brachial artery. When compressing the brachial artery the flow is interrupted, until the applied pressure is slowly dropped to the point where it matches the systolic pressure, producing an intermitted sound train, progressing in a steady rush when the applied pressure is dropped further to become equal to the diastolic pressure. Korotkoff sounds provide a noninvasive mechanism to determine blood pressure, used in every day medical applications with the aid of a stethoscope and an inflatable armband.
1911	Josiah Willard Gibbs (1839–1903); Frederick George Donnan (1870–1956)	Gibbs–Donnan equilibrium for transmembrane electrolytic solutions.
1914–1918		Mapping of brain function with respect to encephalographic location on soldiers while they are still alive with brain tissue exposed (resulting from explosives) in the trenches during World-War I.
1924	Hans Berger (1873–1941)	First official recording of brain activity by means of an electro-encephalogram (EEG). This recording provided a breakthrough in neurologic investigations and the integration of stimulus and response with respect to the respective central and peripheral nervous systems.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1926	Mark Cowley Lidwell (1878–1969) and Edgar Harold Booth (1893–1963)	Rudimentary, but effective, external cardiac pacemaker design.
1929	Otfrid Foerster (1873–1941)	Recognition of the stimulation of the occipital cortex for processing of images acquired by the eye.
1942	Brunó Ferenc Straub (1914–1996)	Description of the “actin” molecule as an integral part to the muscular mechanism of action. As a counterpart to myosin, discovered in 1864. Further refinements were introduced in 1957.
1950	John Alexander Hopps (1919–1998)	Introduction of the “portable” (45 kg) cardiac pacemaker, based on the earlier work by Mark Lidwell (1878–1969) and Edgar Harold Booth (1893–1963) in 1926. This led, with the development of microprocessors, to the first implantable pacemaker in 1958 by William Chardack (1919–2011) and Wilson Greatbatch (1919–2011) in 1958.
1953	Rosalind Elsie Franklin (1920–1958)	Discovery of the macromolecular structure (double helix) and configuration for deoxyribonucleic acid (DNA), as well as contributions to the chemical molecular description of RNA (ribonucleic acid), viruses, coal, and graphite. Rosalind Franklin used X-ray diffraction techniques for her analysis.
1956	Paul Winchell {Wilchinsky} (1922–2005)	Artificial heart (Jarvik 7).
1952		First mechanical blood pump used to assist in open-heart surgery.
1954	Andrew Fielding Huxley (1917–2012) and Alan Lloyd Hodgkin (1914–1998)	Mathematical description of nerve impulses with great accuracy, based on the (steady-state) membrane potential described by Walter Nernst (1864–1941).
~1954	Georg von Békésy (1899–1972)	Fundamental description of the mechanism of action in human hearing.
1954	David E. Goldman (1910–1998)	Goldman equation, describing the membrane potential accounting for the free migration of ions through the cell membrane, adding to the Hodgkin–Huxley equation (Andrew Fielding Huxley [1917–2012] and Alan Lloyd Hodgkin [1914–1998]).
~1955	Willem Johan Kolff (1911–2009)	First commercial artificial kidney; hemodialysis. The design was based on principles introduced by Thomas Graham (1805–1869) in 1854, next to the theoretical chemistry influences of Adolf Fick (1829–1901).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1957	Hugh Esmor Huxley (1924–2013)	Discovery of the integral motion activity of muscular contraction with the assistance of electron microscopy imaging.
1966	Michael E. DeBakey [Michel Dabaghi] (1908–2008)	First left-ventricular assist device implanted in a human.
1968	Viking Olov Björk (1918–2009) and Donald Pearce Shiley (1920–2010)	Introduction of the tilting disk replacement heart valve prostatic.
1968	Giles Skey Brindley (1926–) and Walpole Sinclair Lewin (1915–1980)	Initial implementation of experimental artificial vision using electronic imaging devices, preceding the retinal implant approved in 2013. This work was based on the pioneering efforts by Otfried Foerster (1873–1941).
1981	Uri Dinnar (1939–2014)	Detailed theoretical description of the turbulent flow of cardiovascular fluid dynamics.
1982	Willem Johan Kolff (1911–2009) and Robert Koffler Jarvik (1946–)	First wearable artificial heart; “Jarvik heart.”
1997	Nathan S. Lewis (1956?–)	development of an electronic “nose,” resembling the human olfactory receptor system.
2001	Second Sight Inc.	First experimental artificial eye as a portable system, using a computer interface to the occipital lobe of the brain: ARGUS device.
2013		First FDA-approved retinal implant for regaining vision.

Chemical

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
“Ancient man”		Realization that the following chemical compounds were pure; what we currently consider as elements: gold (8000 BC), silver (<5000 BC), iron (<5000 BC), copper (9000 BC), mercury (<2000 BC), tin (~3500 BC), carbon (3750 BC), and sulfur (2000 BC). Element: a substance consisting of atoms with associated same number of protons (identical atomic number). Elements are the simplest chemical substances, which cannot be broken down further by means of chemical methods. Elements can be converted into other elements only using nuclear methods.
1700 BC	King Hammurabi’s reign over Babylon	Known metals were documented and listed in relation to heavenly bodies.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 600 BC	Thales of Miletus (ca 624 BC–ca 546 BC; known as Thales: Θαλής)	First person to question the basic principles that is documented as such (by Aristotle [384 BC–322 BC]), and specifically the originating substances of matter. Considered the founder of the school of natural philosophy.
450 BC	Leucippus (fifth century BC)	Argued that the universe consists as a structure of atoms and voids.
430 BC	Democritus (of Greece) (460 BC–370 BC)	Proclamation that the atom is the smallest and simplest unit of all matter. All matter is composed of atoms. The first rudimentary introduction of the elementary build block but with no scientific support. Greek word “atomos” (ἄτομος), meaning indivisible.
350 BC	Aristotle (384 BC–322 BC)	Declaration of only four (4) elements defining the existence on earth: fire, water, air, and earth. Matter only has the following properties: wet, dry, hot, or cold.
300	Alchemists	Based on the philosophy of Aristotle, the alchemists believed that “regular” metals could be converted into precious metal, specifically gold, a wishful thought. The item required to perform this conversion was referred to as the elusive “philosopher’s stone.”
“Dark Ages” 500–1300		
1615	Jean Beguin (1550–1620)	First diagram expression for a chemical reaction in a notation that we adhere to today.
1661	Robert Boyle (1627–1691)	End of the era of the Alchemists (perpetuated for 2000 years), partially based on the book by Robert Boyle, <i>The Skeptical Chymist</i> . First “modern chemist.”
1669	Henning Brand (1630–1710)	Documented observation that phosphorus is an element.
~1650–1750	Jöns Jacob Berzelius (1779–1848), John Dalton (1766–1844), and Antoine Lavoisier (1743–1794)	Beginnings of “modern chemistry” indicated by the group of scientists considered the “fathers of modern chemistry.”
ca. 1670	Sir Isaac Newton (1643–1727)	Sir Isaac Newton was one of the prominent proponents and advocates of the atom theory.
1757	William Cullen (1710–1790)	Introduction of the first formula for a chemical reaction.
1774	Antoine Lavoisier (1743–1794)	Discovery of oxygen; and the chemical process of oxidation.
1785	Charles Augustin de Coulomb (1736–1806)	Treatise on electricity: <i>Premier Mémoire sur l’Électricité et le Magnétisme</i> . The unit of electric charge is named after him posthumously. The free electric charge is the electron, which was not fully understood, nor described. The electron does form the basis for strong chemical connections, based on ion formation.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1789	William Higgins (1763–1825)	First use of the term molecule describing a chemical compound consisting of multiple atoms. The word molecule can be traced back to 1678. The expression and concept of the molecule has ties to Rene Descartes (1596–1650) and Robert Boyle (1627–1991).
ca. 1800	John Dalton (1766–1844)	Introduction of the “law of multiple proportions” describing the atomic concept based on chemical reactions taking place in ratios of small whole numbers.
1806	Sir Humphry Davy, 1st Baronet (1778–1829)	Discovery of several alkali next to alkaline earth metals, as well as contributions to the description and discovery of the elemental nature of the elements chlorine and iodine
1810	Joseph Louis Gay-Lussac (1778–1850)	Gas laws and the means to determine the alcohol content of a liquid, still used. Alcohol by volume is referenced as degrees Gay-Lussac in certain countries.
1811	Lorenzo Romano Amedeo Carlo Avogadro di Quaregna e di Cerreto, Count of Quaregna and Cerreto (1776–1856)	Molecular arrangements; molecular quantity in a mole of substance. Avogadro’s law.
1820	Pierre Louis Dulong (1785–1838) and Alexis-Thérèse Petit (1791–1820)	Dulong and Petit law of specific heats.
1841	Claude Bernard (1813–1878)	Recognition of the chemical equilibrium supporting life and functionality of the cell (homeostasis).
1855	Adolf Eugen Fick (1829–1901)	Fick’s diffusion equation for gases and dissolved chemical constituents with respect to membranes.
1857	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Introduction of chemical thermodynamics concepts and definitions and electrodynamics. Hermann von Helmholtz also worked on sensory physiology, inspired by the work of Wilhelm Wundt (1832–1920). He also worked on the functional nerve physiology.
1864	Wilhelm Kühne (1837–1900)	Defined the term “myosin” as a molecular component in the contractile mechanism of action for muscle. Not by long a full description of the functional aspect for the muscle since the remaining components were not discovered until 1942 and later.
1868	Julius Bernstein (1839–1917)	Introduction to the formal mechanism of action for the action potential.
1860	Stanislao Cannizzaro (1826–1910)	Cannizzaro reaction.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1869	Dmitri Ivanovich Mendeleev (1834–1907) and Julius Lothar Meyer (1830–1895)	Both independently introduced the Periodic Table of the Elements, a concise summary of years of documented experimental and theoretical chemistry. The table is both heuristic and mnemonic.
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential, a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1874	Jacobus Henricus van 't Hoff (1852–1911) and Joseph Achille Le Bel (1847–1930)	Two independent observations regarding the optical activity (rotation of polarization direction for transmitted light) for carbon compounds. They both derived that this can be explained by a four (4) way bound carbon atom (chemical saturation).
1879	William Crookes (1832–1919)	Cathode rays and realization that single charged particles must be involved.
1885	Eugene Goldstein (1850–1930)	Discovery of the proton.
1880	Paul-Jacques Curie (1855–1941) and Pierre Curie (1859–1906)	Discovery of electric charges emerging on the surfaces of crystals, which are subjected to shear or normal stress. This is referred to as the piezoelectric effect.
1880	Johannes Diderik van der Waals (1837–1923)	Description of the covalent bond. Van der Waals equation.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron concept; using William Crookes's vacuum tube. The electron itself was at this point not identified.
1897	Marie Skłodowska Curie (1867–1934)	Discovery of radioactive isotopes.
~1890	Niels Ryberg Finsen (1860–1904)	Successful treatment of smallpox with light, building on the early work of Henri de Mondeville (1260–1320).
1888–1889	Walter Nernst (1864–1941)	Definition of the electrochemical potential across a cellular membrane due to the gradient in chemical concentration for several elements. This process produces a “half-cell potential,” similar to what is found in batteries. This can be placed in perspective to the first “battery” that is practical in use, designed by Alessandro Giuseppe Antonio Anastasio Volta (1745–1827) in 1800.
~1900	Oscar Raab (1876?–1986) and Giorgio Marcacci (18??–19??)	Discovery of the phototoxicity of light, specifically in the eradication of cancer.
1906	Dmitri Ivanovich Mendeleev (1834–1907)	Periodic Table of Elements.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1911	Josiah Willard Gibbs (1839–1903) and Frederick George Donnan (1870–1956)	Gibbs–Donnan equilibrium for transmembrane electrolytic solutions.
1909	Robert Andrews Millikan (1868–1953)	Measurement of the mass of the electron.
1914	Henry Gwyn Jeffrey Moseley (1884–1915)	X-ray spectrograms of the elements which assisted in the establishment of the identity of the ordinal number of respective elements in the periodic table associated with its nuclear charge: atomic number.
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure and quantum theory.
1916	Gilbert Newton Lewis (1875–1946)	Description of the shell filling for atomic electrons, and the related covalent bond and the concept of valence electrons.
1917	Ernest Rutherford, 1st Baron Rutherford of Nelson (1871–1937)	Discovery of the proton.
1926	1928: Paul Dirac (1902–1984); 1929: Dmitri Vladimirovich Skobeltsyn (1892–1990); and 1932: Carl David Anderson (1905–1991)	Discovery of positron. Generally, Carl Anderson is credited with the formal discovery (Nobel Prize).
1926	Jean Baptiste Perrin (1870–1942)	Physical proof providing the existence of molecules.
1927	Wolfgang Ernst Pauli (1900–1958), Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles. This formed the foundation for the development of the NMR imaging system: nuclear magnetic resonance (MRI).
1928	Sir Chandrasekhara Venkata Raman (1888–1970)	Raman spectroscopy; indicating the energy levels in atoms and molecules.
1931	Linus Carl Pauling (1901–1994)	Description of the general and detailed nature of various types of chemical bonds.
1932	James Chadwick (1891–1974)	Discovery of the neutron.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more.
1924	Niels Henrik David Bohr (1885–1962)	Introduction of the term: “element.” This idea was formed based on Wolfgang Pauli’s (1900–1958) exclusion principle. The element concept has been around for millennia.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model of atomic nuclei.
1953	Rosalind Elsie Franklin (1920–1958)	Discovery of the macromolecular structure (double helix) and configuration for deoxyribonucleic acid (DNA), as well as contributions to the chemical molecular description of RNA (ribonucleic acid), viruses, coal, and graphite.
~1955	Willem Johan Kolff (1911–2009)	First commercial artificial kidney; hemodialysis. The design was based on principles introduced by Thomas Graham (1805–1869) in 1854, next to the theoretical chemistry influences of Adolf Fick (1829–1901).
1992	Kenneth Kin Man Kwong (1948–)	Introduction of “functional MRI.” In 2013 the sugar consumption was measured in cancer cells with respect to normal cells for diagnostic verification.

Computational

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
9000 BC–6500 BC	Ishango Bone	Bone with the first prime numbers carved in order.
3500 BC	Mesopotamian clay tablets	Clay carvings with geometrical shapes, fractions, and logarithm and a list of “squares.” Most was published on a base of 60, not our current 10-base
1600 BC	Rhind papyrus	Papyrus scrolls with mathematical equations and fractions.
1750 BC–500 BC	Vedic period (India)	Advanced civilization with a great number of mathematical revelations. Algebra, trigonometry, and geometry expression by Lagadha, approx. 1300 BC; approx. 800 BC and Yajnavalkya also approx. 800 BC.
600 BC	Apastambha (ca. 630–560 BC)	Hindu (India) scholar that expressed the value of pi (π) well before the documented use in the Egyptian/ Babylonian mathematics. This relates to the calculations of the circumference and area of circle and sphere. Apastambha may have described the angular concepts that are attributed to Pythagoras at least a century prior.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
600 BC	Thales of Miletus (ca. 640 BC–546 BC)	First introduction to finite (differential) approximation. Father of philosophy. Also described the use of triangulation to measure dimensions of remote objects (i.e., height of pyramids). Greek philosopher who supposedly studied under the Egyptians (Mesopotamia).
530 BC	Pythagoras of Samos (ca. 578–505 BC)	Student of a student of Thales. Introduced the formal concepts in geometry.
450 BC	Zeno of Elea (ca. 495–435 BC)	Introduced the concept of infinitesimal steps (infinitesimally small; approach of a turtle that is moving away, paradox).
350 BC	Aristotle [of Stagira] (384–322 BC)	Teacher to Euclid. Documented axioms and proofs. Introduced the initial concepts of the wave theory for light, although not accepted for almost 2000 years.
300 BC	Euclid [of Megara and Alexandria] (ca. 322–275 BC)	“Father of modern mathematics.” Introduced the Euclidean space for model formation representing real-life situations. He described spherical geometry and other complex geometrical forms such as the cone.
250 BC	Archimedes of Syracuse (287 BC–212 BC)	Student at the school of Euclid, most likely after Euclid’s death. number theory, and square roots. Additional mathematics applied to specific physical phenomena such as buoyancy.
ca. 130	Claudius Ptolemaeus of Alexandria (ca. 90–168)	Introduction of various mathematical rules and theorems that allowed the introduction of more complex mathematics as seen in the following centuries. Ptolemy’s theorem.
ca. 250	Liu Hui (ca. 220–280) [China]	Incorporation of negative numbers in mathematical expressions and arithmetic. Building on the work of Chang Tshang (ca. 200–142 BC) also from China. Liu Hui is considered to be one of China’s greatest mathematicians. He also formalized the decimal system. The number zero had a special meaning, introducing the initial concept of the “singularity.” Hui also described the process for solving a series of linear equations (solving for multiple unknowns).
ca. 500	Aryabhata (476–550) [India]	Advanced mathematics, including series resembling the “Taylor series.”
ca. 850	Ya’qub ‘Abu Yusuf’ ibn Ishaq al-Kindi (803–873) [Iraq]; Al-Kindi referred to as Alkindus in the West	Popularized the implementation of the decimal system, developed spherical geometry, and many other science and engineering topics and pioneered the concept of cryptography (code breaking). (Al-Kindi, called the Arab Philosopher, however not one of the greatest of mathematicians, but was one of the most influential scientists between Aristotle (384 BC–322 BC) and Leonardo da Vinci (1452–1519).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1000	Mohammed ibn al-Hasn (Alhazen) 'Abu Ali' ibn al-Haytham al-Basra (965–1039) [Iraq, Egypt]	Mathematical descriptions in optics and astronomy. The work of Al Hazen anticipated Newton's first law of motion (Sir Isaac Newton [1643–1727]); the "principle of least action."
ca. 1200	Leonardo 'Bigollo' Pisano (Fibonacci) (ca. 1170–1245) [Italy]	Known today as "Fibonacci." Provided the persuasion for Europe to the decimal system, also using fractions. Defined congruous in addition to the theorems to provide the supporting proof. The work of Fibonacci has great relevance in biomedical applications, if not alone the Fibonacci code found for instance in the "veins" in a leaf of a tree.
1202	Leonardo Fibonacci (1170–1240) [Leonardo Bonacci/Leonardo of Pisa, Leonardo Pisano Bigollo]	First lecture text on algebra; introduction of the Fibonacci sequence, found in several natural phenomena.
ca. 1320	Levi ben Gerson 'Gersonides' (1288–1344?)	Various basic scientific advancement resulted from his mathematical efforts. One specific example is the realization that in musical notes there are no consecutive harmonic numbers larger than (8, resp. 9).
1475	Luca Pacioli (1445–1572)	Collaborator with (mentor to) Leonardo da Vinci (1452–1519). Published work on geometry (in particular perspective), and accounting. One specific work on the Euclidean mathematics was a great step forward in conceptual mathematics.
1500	Leonardo da Vinci (1452–1519)	Renaissance man. Formal description of physical phenomena based on the state-of-the-art mathematical definitions, inventor, and prolific writer.
ca. 1500	Nicolaus Copernicus (1472–1543)	Astronomy and cartography. Telescope design and construction and associated calculations of the locations of observations on stars and planetary movements.
1575	Simon Stevin (1549–1620)	Civil engineering supported by stringent mathematical calculations. Windmill design, working as an engineering architect. Simon Stevin introduced the real number concept and the square root sign. Formally introduced the formal concept of decimal system in western Europe. Predated some observation and conclusion attributed to Augustin-Louis Cauchy (1789–1857).
ca. 1600	John Napier 8th of Merchistoun (1550–1617)	Formal introduction of the logarithm concept. Inventor of a rudimentary but pioneering calculator, next to the abacus.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1600	Galileo Galilei (1564–1642)	Described laws of motion (falling bodies; gravitational acceleration) and inertia, before Sir Isaac Newton (1643–1727). Invented the pendulum clock and many more engineering feats. Additional contributions by Galileo Galilei are in astronomy, specifically the discovery of Jupiter’s moons. Galileo also wrote about infinite equinumerosity, what is known as the “Hilbert’s Hotel Paradox” (David Hilbert [1862–1943]; ‘Hilbert Space’). Galileo once wrote “Mathematics is the language in which God has written the universe.”
ca. 1600		Acceptance of the decimal system in Europe. Early evidence of the decimal system dates as far back as 3000 BC China (used in the abacus). Furthermore, the Greek mathematicians also used the decimal system. (Northern) Europe prior to this used a system based on halves, still in use in the United States of America.
ca. 1600	Johannes Kepler (1571–1630)	As the understudy to Tycho Brahe (1546–1601) {Tyge Ottesen Brahe} Johannes Kepler used the astronomical data collected by Tycho Brahe to develop a detailed calculation for the planetary motion based on his derived elliptical orbits in contrast to the up to that time assumed circular orbits.
ca 1620	René Descartes (1596–1650)	Description of Euler’s (Leonard Euler [1707–1783]) polyhedral theorem, pre-dating Euler. Description of a “vortex” theory for gravitation, next to various laws of motion.
ca. 1625	Francesco Bonaventura de Cavalieri (1598–1647)	Worked in optics and astronomy and proposed several limit series (theorems) for known algebraic problems, often based on his trigonometry interests. In specific he described the area for a spherical triangle.
1647	Bonaventura Francesco Cavalieri (1598–1647)	Derivation of the relationship between the radii of curvature for the respective two surfaces of a thin lens and the resulting focal length.
ca. 1650	Pierre de Fermat (1601–1665)	Developed infinitesimal (elementary) calculus. Instrumental in the development of the mathematical description of the optical refraction principle. Several of Fermat’s efforts extended beyond the two-dimensional plane where most mathematicians were comfortable.
ca. 1650	Gilles Personne de Roberval (1602–1675)	Developed the initial principles for integration, basing his work on the publications from Archimedes (287 BC–212 BC), rather than on Francesco Bonaventura de Cavalieri (1598–1647). Roberval was instrumental in the development of cartography. Gilles de Roberval also worked alongside Blaise Pascal (1623–1662) on several experiments.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1650	Blaise Pascal (1623–1662)	Designed several calculator machines. Worked on pressure and introduced “the scientific method.” Corresponded with Pierre de Fermat (1601–1665) on his ideas about probability and geometry. He also followed the work of Evangelista Torricelli (1608–1647) closely.
ca. 1650	Christiaan Huygens (1629–1695)	Developed the inverse square law of gravitation (before Sir Isaac Newton [1643–1727]) and various mechanical devices, including a reliable pendulum, leading to an accurate time-keeping mechanism. The Huygens’ principle was a mathematical essay on the wave properties of light, still overpowered by the corpuscular interpretation by Sir Isaac Newton.
1665	James Gregory (1638–1675)	Inventor and designer of a reflecting telescope. Furthermore, Gregory developed several mathematical expressions, including a series expression for the inverted tangent. James Gregory anticipated the Cauchy convergence requirement in his analysis (Baron Augustin-Louis Cauchy [1789–1857]).
ca. 1670	Sir Isaac Newton (1643–1727)	Introduced revolutionary advances in optics, mechanics, thermodynamics, and acoustics and astronomy-based mechanics (astrophysics). Newton also developed a series to define the “arcsin” function. Sir Isaac Newton is most known for his formal introduction of the gravity concept, but had earlier work to build on at his disposal. Isaac Newton was one of the prominent proponents and advocates of the atom theory. Newton also introduced one of the first colour–hue wheels. Sir Newton was a master at geometry, solving several problems that were so far unsolved. In 1687 Sir Isaac Newton published: <i>Philosophiae Naturalis Principia Mathematica</i> .
1675	Gottfried Wilhelm von Leibniz (1646–1716)	Formal introduction to the calculus concepts. Leibniz discovered and proved a very effective identity series for pi (π): $\pi/4 = 1 - 1/3 + 1/5 - 1/7 + 1/9 - \dots$. Additionally, Leibniz introduced the mathematical notations that are still used to date.
1684	Jacob Bernoulli (1654–1705)	Developed integral and differential equations. Worked on fluid dynamics. Close friend of Gottfried Wilhelm von Leibniz (1646–1716). Older brother to Johann Bernoulli (1667–1748).
1700	Abraham De Moivre (1667–1754)	Contributed significantly to the development of probability theory, with close ties to Pierre Simon Laplace (1749–1827), following in his footsteps.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1700	Johann Bernoulli (1667–1748)	Johann learned from his older brother Jacob Bernoulli (1654–1705), and from Gottfried Wilhelm von Leibniz (1646–1716), and became a tutor to Leonhard Euler (1707–1783). Johann Bernoulli's son, Daniel Bernoulli (1700–1782) was just as much a polymath as his father and grandfather, next to his contributions to the description of gas dynamics: "Bernoulli's Law."
1715	Brook Taylor (1685–1731)	Rudimentary description and discovery of the Taylor Series described by the Scottish mathematician James Gregory (1638–1675) and later introduced formally by the English mathematician Brook Taylor (1685–1731).
1740	Daniel Bernoulli (1700–1782)	Son of Johann Bernoulli (1667–1748). He developed partial differential equation and used the "Fourier series" prior to the publication by Jean-Baptiste Joseph Fourier (1768–1830). The work of Daniel Bernoulli that he is most known for is in fluid dynamics and gas mechanics.
1750	Leonhard Euler (1707–1783)	Most prolific mathematician in the known history of mathematics. Euler developed the polyhedral theorem (with some suspicion that this may be traced back to René Descartes (1596–1650). Euler revolutionized the design of pumps based on his fluid dynamic theories, including turbine equations. Other theoretical interests of Leonhard Euler were optics, astronomy, acoustics, mechanics, and music. In his astrophysics work he developed a formulation to determine the moon orbit in a three body motion problem; first ever. Additional theoretical efforts defined the rotational motion of rigid bodies of various configurations. Euler also introduced the definition for the square root of negative one as the letter i , next to several other mathematical standard expressions for algebraic terms. Leonard Euler also introduced the exponential expression with the use of the complex number by means of sin and cosine: $e^{ix} = \cos x + i \sin x$. Euler popularized the use of the letter sigma for a series summation.
1760	Jean le Rond d' Alembert (1717–1783)	d'Alembert laid the foundation for modern meteorology with his mathematical descriptions of the formation of wind. Other work include collision dynamics, hydrodynamics, and vibration. Jean d' Alembert proved that every polynomial has a complex root (d' Alembert–Gauss theorem). Jean le Rond d' Alembert may have been the first person to express time as the fourth dimension, especially with respect to the complex physics phenomena evolving.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1760	Johann Heinrich Lambert (1727–1777)	Even after dropping out of school due to family circumstances at the age of 12, Johann Lambert became a renowned and influential mathematician. Johann Lambert made great contributions to astrophysics calculations, illustrating the existence of star clusters. Lambert also build the first operational photometer. In addition, on a geophysics level he contributed to the cartography and land movement dynamics.
1780	Joseph-Louis (Comte de) Lagrange (1736–1813) [Giuseppe Lodovico Lagrangia]	Introduced a range of polynomials, and introduced “group theory.” The use of transforms for functions in order to facilitate solving them was introduced before (or in conjunction with) Pierre Simon, Marquis de Laplace (1749–1827). Lagrange introduced the use of comma notations for first and second order derivative.
1799	Pierre Simon, marquis de Laplace (1749–1827)	Laplace Law; Laplace transform to solve complex equations and his work on celestial mechanics (astrophysics). The Laplace transform converts a temporal function into a frequency domain function.
1800	Adrien Marie Legendre (1752–1833)	Introduced the Legendre polynomials concepts and Legendre transform to aid in solving complex equations by conversion of spatial parameters. Legendre worked on spherical geometry. Legendre made significant advances in the solution technique applied to elliptic integrals.
1800	Jean Baptiste Joseph Fourier (1768–1830)	The Fourier transform is one of the most widely used mathematical tools in all fields of physics and engineering; converting any periodic or instantaneous event into a series (superposition) of sin and cosine terms, mathematical solving technique using increasing orders of perturbation. The Fourier transform has many trades of the Laplace transform, referring to the time to frequency conversion. In thermodynamics, Fourier introduced his heat equation that provides significant practical applications.
1808	Étienne-Louis Malus (1775–1812)	Mathematical analysis of the concept of light. Verified the principles introduced by Christiaan Huygens (1629–1695). Observed the light reflecting from the windows, uncovering an effect that was later attributed to the polarization of light resulting from reflection. Member of the mathematics section of the Institut d’Égypte resulting from his travels with Napoléon Bonaparte (1769–1821). Introduction of Malus’ law.
1810	Johann Carl Friedrich Gauss [Gauß] (1777–1855)	Gauss constructed the theory of complex numbers in the form we use today. In astrophysics Gauss derived the orbit of an asteroid (Ceres), observed during his life-time, and predicted its return path around the Sun with great accuracy. Carl Friedrich Gauss is most known for his practical contributions to the field of electricity and magnetism: Gauss’s law; magnetic flux theorem.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1810	Siméon Denis Poisson (1781–1840)	Poisson's analysis of the wave theory of light contributed to the evolution and understanding of interference principles and applications.
1820	William George Horner (1786–1837)	Introduction of the methodology for solving and calculating polynomials (roots): Horner's method. The methods were actually already described 600 years prior by the Chinese mathematician Qin Jiushao (秦九韶) (ca. 1202–1261).
ca. 1825	Baron Augustin-Louis Cauchy (1789–1857)	Pioneer in mathematical and structural analysis of data. Formally introduced several of the modern concepts of calculus. Cauchy also introduced the concept of convergent series, in order to obtain a finite solution.
1840	Carl Gustav Jacob Jacobi (1804–1851)	His work involved the development of what is known as cubic reciprocity, which was found very helpful by Carl Friedrich Gauss (1777–1855). Jacobi also worked closely with Sir William Rowan Hamilton (1805–1865), and he developed his own mathematical approach, the Jacobian matrix and determinants in vector calculus used to solve multiple co-dependent relations in multiple equations; specifically applied to partial derivatives. The Jacobian applies primarily to individual points in data space.
1840	Johann Peter Gustav Lejeune Dirichlet (1805–1859)	Dirichlet interpreted the work of Carl Friedrich Gauss (1777–1855), revealing various uncovered items. Gustav Dirichlet was a tutor, respectively mentor, to Sir William Rowan Hamilton (1805–1865), Bernhard Riemann (1826–1866) and Leopold Kronecker (1823–1891).
1842, 1851	Sir George Gabriel Stokes, 1st Baronet (1819–1903)	Fluid dynamics Stokes equation, aberration of light with respect to the wave properties of light. Additional work of Gabriel Stokes was in the initial full theoretical description of polarization of electromagnetic radiation.
1850	Sir William Rowan Hamilton (1805–1865)	Sir Hamilton is most known for his reformulation of Newtonian mechanics: Hamilton mechanics. Hamilton mechanics can be considered an essential building block to the development of quantum mechanics. Sir William Hamilton introduced the principles leading to the formulation of the Hamiltonian operator used in quantum mechanics, defining the total energy of a system.
1850	George Boole (1815–1864)	Known for the Boolean algebra and logic. The work of George Boole inspired Claude Shannon (1916–2001).
1860	Georg Friedrich Bernhard Riemann (1826–1866)	The work of Bernhard Riemann was instrumental in the development of the theory of general relativity and the supporting mathematical evaluation.
1865	James Clerk Maxwell (1831–1879)	Electromagnetic theory.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1874	Marie Alfred Cornu (1841–1902)	Described a graphical approach to the solution of diffraction problems: Cornu spiral.
1880	Leopold Kronecker (1823–1891)	Introduction of the “Kronecker Delta”, isolating the one single location in function space where a function can be considered rational. His studies primarily focussed on the ergodic theoretical aspects, describing dynamic systems.
1899	Jules Henri Poincaré (1854–1912) and Jacques Salomon Hadamard (1865–1963)	Geodesic flow; mathematical and analytical description.
1890	Jules Henri Poincaré (1854–1912)	Introduction of methods and means for deriving accurate topographical data. Some of the work of Poincaré revolved around defining the geometry of the universe. Poincaré also contributed to fluid dynamic modeling in addition to the description of celestial motion.
1895	Diederik Johannes Korteweg (1848–1941) and Gustav de Vries (1866–1934)	Diederik Korteweg and his student Gustav de Vries derived a nonlinear partial differential equation defining the propagation of waves in shallow water. The Korteweg–de Vries (KdV) equation describes the solitary wave described by John Scott Russell (1808–1882). The KdV equation has had an important implications for the development of the mathematical description of solutions.
1900	Samuel Giuseppe Vito Volterra (1860–1946)	Description and formulation of cylindrical waves. Volterra became involved in the biological cause and effect, respectively predator–prey aspects pioneering the field of mathematical biology.
1900	David Hilbert (1862–1943)	Hilbert space: vector space designed to accommodate an infinite number of dimensions, with respect to the three-dimensional Euclidean space. The Hilbert spatial interpretation forms an indispensable tools in solving for partial differential equations, as well as pertaining to quantum mechanics, and Fourier analysis. In Fourier analysis this applies to applications in signal processing and heat transfer. Hilbert space is an ergodic theory, which provides the mathematical foundations of certain thermodynamics topics.
1905	Albert Einstein (1879–1955)	Energy–mass equivalence hypothesis introduced. Einstein also published his theoretical interpretation of the movements of object, specifically approaching the speed of light in his special theory of relativity and general theory of relativity. In 1917 he published his predictions on stimulated emission and hence the preliminary description of the operations of a LASER. Additional mathematical work eludes to quantum theoretical approach.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1908	Hermann Minkowski (1864–1909)	Developed a geometrical interpretation of the special theory of relativity in which time and the three space coordinates all had the same validity in a four-dimensional continuum.
1910	Amalie Emma Noether (1882–1935)	Master of abstract algebra. Amalie Noether also introduced the concept of conservation laws based on the symmetry in nature and physics and engineering.
1910	Hermann Klaus Hugo (Peter) Weyl (1885–1955)	Weyl studied under David Hilbert (1862–1943) and was also close to Amalie Emma Noether (1882–1935). Hermann Weyl uncovered a gauge invariance and with his interpretation of Riemann surfaces his teachings form the basis of many aspects supporting the theoretical explanation in modern physics concepts. Weyl also contributed to the efforts of Erwin Schrödinger (1887–1961).
1910	Edmund Georg Hermann Landau (1877–1938)	Known for his work on prime number theory.
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure and quantum theory.
1921	Alfred Landé (1888–1976)	Mathematician who introduced the Landau factor for an electron with both self-rotation spin and orbital angular momentum.
1924	Sir John Edward Lennard-Jones (1894–1954)	Definition of the attraction between two neutral molecules or atoms: Lennard-Jones potential.
1924–1945	Harry Nyquist (1889–1976) [Harry Theodor Nyqvist]	Combining mathematical approach to telecommunications and electronic engineering. His work started out to find the most elegant manner to suppress thermal noise. The Nyquist theorem, also referred to as the Nyquist–Shannon theorem, defines the sampling rate for period signals to ensure capturing all information contained in the transient signals.
1922	Erwin Rudolf Josef Alexander Schrödinger (1887–1961) and Hermann Klaus Hugo Weyl (1885–1955)	Introduction of the quantum mechanical principles, supporting the understanding of high energy physics phenomena such as the atomic structure.
1923	John von Neumann (1903–1957) [original name: Neumann Janos Lajos]	Introduced finite element methodology (also known as Monte Carlo simulation), integration of random number generation. He was also instrumental in the design of thermonuclear bombs as well as significantly advanced the field of hydrodynamics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1924	Satyendra Nath Bose (1894–1974) [সত্যেন্দ্র নাথ বসু] and Albert Einstein (1879–1955)	Introduction of the Bose–Einstein statistics: one of two potential manners of energy occupation for a collection of noninteracting indistinguishable particles with respect to a set of available discrete energy states, this applies to thermodynamic equilibrium only. At extreme low temperatures these energy levels for bosons can result in a joining of states: condensation, the Bose–Einstein condensate.
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all objects in motion. Matter wave, propagating with the de Broglie wavelength.
1925	Wolfgang Ernst Pauli (1900–1958)	Pauli exclusion principle for atomic energy levels.
1925	Werner Heisenberg (1901–1976)	Introduction of quantum mechanics, specifically in matrix formulation. Heisenberg also introduced the “uncertainty principle”; two parameters describing the same item or phenomenon cannot be known simultaneously with exact accuracy, such as momentum and position, but are inherently linked to each other with a product that yields the reduced Planck constant divided by two or greater.
1926	Eugene Paul Wigner (1902–1995)	Series publications on the application of group theory in quantum mechanics. Eugene Wigner shared the Nobel Prize in Physics jointly with Maria Goeppert-Mayer and Johannes Hans Daniel Jensen (1907–1973) in 1963.
1927	Wolfgang Ernst Pauli (1900–1958), Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles. This formed the foundation for the development of the NMR imaging system: nuclear magnetic resonance (MRI).
1935	Enrico Fermi (1901–1954)	Developed Fermi–Dirac statistics, although independent from Paul Dirac (1902–1984) but simultaneously. The Fermi–Dirac statistics applies to fermions; while the counterpart that it does not include are referred to as bosons. Fermi worked on X-ray crystallography, as well as energy levels in semiconductor structures. The Fermi level concept for electrons in atomic energy approximating absolute zero ties directly in with the Pauli exclusion principle. Fermi worked with and studied under Max Born (1882–1970), Werner Heisenberg (1901–1976), Pascual Jordan (1902–1980), Paul Ehrenfest (1880–1933), Hendrik Lorentz (1853–1928) Samuel Goudsmit (1902–1978), Jan Tinbergen (1903–1994), and Albert Einstein (1879–1955). Fermi concluded that beta decay from the nucleus formed another energetic particle and determined it to be real and named it a neutrino.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1935	Paul Adrien Maurice Dirac (1902–1984)	Developed Fermi–Dirac statistics, although independent from Enrico Fermi (1901–1954) but simultaneously.
1936	Inge Lehmann (1888–1993)	Description of the numerical assessment of data obtained during earthquakes (seismological data) and the image formation of the structure of the earth's structure, divided in shells with different material phase and composition. The image formation is based on what is referred to as S-waves and P-waves. Inge Lehmann discovered and described the shape, size, and composition (rudimentary) of the earth's inner core.
1945	Claude Elwood Shannon (1916–2001)	Sampling theory, minimum sampling rate for correct acquisition of periodic data. Sometimes introduced as the “father of information theory.” The work of Shannon paralleled that of Harry Nyquist (1889–1976).
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction and mathematical description of the nuclear shell model for atomic nuclei.
1972	Stephen Hawking (1942–), Jacob Bekenstein (1947–2015)	Thermodynamics of black holes.
1973	Sheldon Glashow (1932–), Abdus Salam (1926–1996), Steven Weinberg (1933), Carlo Rubbia (1934–) and Simon van der Meer (1925–2011)	Reference to a presumed, but so far unconfirmed unified field theory; based on the work of James Clerk Maxwell (1831–1879), Hans Christian Ørsted (1777–1851), and Michael Faraday (1791–1867). However, a better understanding of electro-weak interaction and electro-strong forces has certainly evolved from this research and mathematical analysis and modeling.
1995	Andrew Wiles (1953–)	One of the theorems introduced by Pierre de Fermat (1601–1665) in his “Arithmetica” is proved. The original theorem states the following: “no three positive integers a , b , and c can satisfy the equation $a^n + b^n = c^n$ for any integer value of n greater than two.”
1995	Edward Witten (1951–)	Introduction of “M-Theory”; also known as string theory, supported by Stephen Hawking (1942–). The M-theory attempts to reconcile quantum theory with gravity, but remains incomplete up to the date of this publication.

Dynamics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 6000 BC	Egypt	First recorded drawings of rudimentary water crafts.
ca. 4000 BC	Eastern Europe	First recorded drawing of craft with rudimentary wheels.
ca. 3300 BC	Egypt	Drawings of sailboat.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
350 BC	Aristotle (384 BC–322 BC)	Founder of the Lyceum school of analytical thinking in Macedonia. Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle supposed an external force (acting during flight) perpetuating the projectile motion of a ballistic object.
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Description of the “nature of objects.” Thales believed that objects are alive; part of the stream of thought by the “Hylozoists.”
ca. 250 BC	Archimedes (287 BC–212 BC)	Hand-operated cork-screw water pump. The philosophies of Archimedes shaped the development process of modern engineering.
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca. 80 BC–10 BC)	First recorded use and description of the mechanism of action of a steam-operated engine: Æolipile; described in <i>De Architectura</i> .
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεὺς], (10–70)	Second recorded use of steam to provide power to a machine; Æolipile.
650		First recorded use of wind mills and wind energy in the Persian Empire.
1010	Eilmer of Malmesbury, 11th century Benedictine monk	First documented successful flight, performed with a wooden frame lined with parchment, traveling approximately 200 meter in free fall from a 18-meter elevation.
1206	Al-Jazari (1136–1206) [Turkey]; Badi’ al-Zaman Abū al-’Izz ibn Ismā’il ibn al-Razāz al-Jazarī (بْنُ الْعِزِّ أَبُو الزَّمَانِ بِسَدِيعِ الْجَزَارِيِّ الرَّزَازُ بْنُ إِسْمَاعِيلَ)	Publication of <i>Book of Knowledge of Ingenious Mechanical Devices</i> . Description of mechanical devices and mechanism of action.
1245	Thomas Aquinas (1225–1274)	Reformulation of the dynamic concepts of Aristotle (384 BC–322 BC).
1500	Leonardo da Vinci (1452–1519)	Formal description of physical phenomena based on the state-of-the-art mathematical definitions. Description of several machines, including “flying machines,” and a rudimentary theoretical discourse on the respective mechanism of action for several dynamic systems. Description of early friction concepts.
ca. 1600	Galileo Galilei (1564–1642)	Description of laws of motion (falling bodies; gravitational acceleration), projectile motion (ballistics), and inertia, before Sir Isaac Newton (1643–1727). Invented the pendulum clock and many more engineering feats.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” power by gunpowder.
ca. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced several laws of motion. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action–reaction, gravitational acceleration, inertia, and force with respect to acceleration. Introduction of the three laws of motion.
1699	Guillaume Amontons (1663–1705)	Formal introduction of the concept of friction, based on the rudimentary introduction by Leonardo da Vinci (1452–1519).
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine.
1712	Thomas Newcomen (1664–1729)	Construction of an “atmospheric” steam engine.
1743	Jean-Baptiste le Rond d’Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> .
1750	Leonard Euler (1707–1783)	Introduction of the coefficients representing kinetic and static friction.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.
1781	Charles-Augustin de Coulomb (1736–1806)	Verification of the friction principles that were introduced by Guillaume Amontons (1663–1705).
1827	Benoît Fourneyron (1802–1867)	First water turbine.
1833	Arthur Jules Morin (1795–1880)	Differentiation between sliding and rolling friction.
1840	Claude-Louis Navier (1785–1836) and George Gabriel Stokes (1819–1903)	Fluid dynamics, friction concepts.
1866	Osborne Reynolds (1842–1912)	Friction description with respect to fluid dynamics concepts.
1879	Karl Friedrich Benz (1844–1929)	Invention of the internal combustion engine-driven automobile. Close collaboration with Gottlieb Wilhelm Daimler (1834–1900).
1880	Paul-Jacques Curie (1855–1941) and Pierre Curie (1859–1906)	Discovery of electric charges emerging on the surfaces of crystals which are subjected to shear or normal stress. This is referred to as the piezoelectric effect.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1880	Johannes Diederik van der Waals (1837–1923)	Description of the covalent bond. Van der Waals equation.
1888	John Boyd Dunlop (1840–1921)	Invention of the pneumatic tire.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.
1899	Jules Henri Poincaré (1854–1912) and Jacques Salomon Hadamard (1865–1963)	Geodesic flow; mathematical description and physical analysis. With further analysis by George David Birkhoff (1884–1944) in 1927.
1900	Rudolf Christian Karl Diesel (1858–1913)	Proof of principle that an engine (“diesel engine”) can operate on peanut oil. The mechanism was based on the efforts by Herbert Akroyd Stuart (1864–1927) in 1885.
1901	Ferdinand Porsche (1875–1951)	First hybrid automobile, internal combustion engine is used to rotate an electric generator, which in turn provides the power to operate a hub motor; an electric motor that is part of the axle of the automobile, attached to the wheel (ref. hubcap of the wheel).
1905	Orville Wright (1871–1948) and Wilbur Wright (1867–1912)	First sustained flight with a powered fixed-wing aircraft.
1909	Robert Andrews Millikan (1868–1953)	Measurement of the mass of the electron.
1915	Clinton Edgar Woods (1863–1930)	Hybrid automobile, powered by internal combustion engine as well as electric motor. Woods Motor Vehicle Company.
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure and quantum theory.
1917	Ernest Rutherford, 1st Baron Rutherford of Nelson (1871–1937)	Discovery of the proton.
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all object in motion. Matter wave, propagating with the de Broglie wavelength.
1927	Wolfgang Ernst Pauli (1900–1958) Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept, as a component of a broad range of quantum mechanical principles.
1924	Felix Heinrich Wankel (1902–1988)	Development and operation of the rotary engine (“Wankel motor”).
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1937	Sir Frank Whittle (1907–1996)	Introduction of the jet engine.
1947	Chuck Yeager (1923–)	Breaking of the sound barrier during level flight.

ElectroTechnology_Electronic

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
c. 600 BC	Thales of Miletus (c. 624 BC–c. 546 BC; known as Thales: Θαλῆς)	Description of static electricity. Static electricity could specifically be induced by rubbing amber with animal fur, hence the association of the electric charge with the Greek word “amber” (referred to in Greek as electrum [ἤλεκτρον, translated as <i>ēlektron</i>]) meaning electron. Amber is solidified and hardened tree sap, resin.
500 BC	Leucippus (5th century BC)	Potential Greek philosopher who mentioned the fact that all matter is made up of indivisible, imperishable constituents, and referred to them as atoms. These atoms were not specific to the nature of the element in question under this hypothesis, but assumed to be all alike.
450 BC	Democritus (460 BC–370 BC)	Proposed the concept of the atomic nature of matter, presumably based on his work under Leucippus (5th century BC), but not confirmed as the original source.
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man,” involved in all aspects of cultural evolution, science, engineering, politics, and art.
1503	Gregor Reisch (1467–1525)	Detailed outline of the state-of-the-art science and engineering knowledge to date, including human anatomical drawings in the publication <i>Margarita philosophica</i> . The total works of Gregor Reisch form a series of 12 books compiling an encyclopedia describing topics ranging from Latin grammar, to dialectics, rhetoric, arithmetic, music, geometry, astronomy, physics, natural history, physiology, psychology, and ethics
1512	Gregorius Reisch (1467–1525)	Introduction of the concept of the theodolite, used for topography and geographic location determination.
1543	Nicolaus Copernicus (1473–1543); Alias of Niclas Koppernigk	Introduction of the heliocentric model for the earth, sun, and planets close by. This follows the statement by the astronomer from Greece: Aristarchus of Samos (c. 310–c. 230 BC), made more than 1700 years prior. The scientific observations made by Copernicus were validated by Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1600	Sir William Schwenck Gilbert (1544–1603)	Experimentalist. Description of the generation of “electricity” [electricus] when rubbing amber with fur. The term electron is derived from the Latin word used to describe the material amber: electrum, or the Greek word <i>ēlektron</i> : ἤλεκτρον.
ca. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re) introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei was remanded under house arrest by the Roman Inquisition for his views and teachings where he died after 9 years. This was the trailing end of the Renaissance period.
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits. Descartes also made an illustration of the earth’s magnetic field configuration in 1644, in his model the moon and celestial objects participated in the formation of the path of the magnetic field lines. Based on the limited experimental observations available in his time the premise was still not bad.
1632	Evangelista Torricelli (1608–1647)	Introduction of the barometer; essential in weather prediction; meteorology.
1650	Blaise Pascal (1623–1662)	Pascal’s law, pressure in a container applies an equal force on all surface of the enclosure.
1657	Otto von Guericke (1602–1686)	Electrostatic repulsion.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas as a potential “shock-absorber,” acting similar to a spring.
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” powered by gun powder. Huygens introduced several concept of mechanical engineering and described the mechanism of shock waves. Christiaan Huygens is most known for his lens manufacturing and optical design of telescopes. The mathematical efforts of Christiaan Huygens in probability theory were far advanced and he collaborated with the mathematician Pierre de Fermat (1601–1665) from France.
1679	Denis Papin (1647–c. 1712)	Pressure and thermodynamic and mechanical impacts.
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced several laws of motion. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action–reaction, gravitational acceleration, inertia, and force with respect to acceleration. Introduction of the three laws of motion.
1698	Francis Hauksbee the Elder (1660–1713)	Repeated the experiment of electrostatic repulsion performed by Otto von Guericke (1602–1686). Francis Hauksbee illustrated the preliminary concept of the gas discharge lamp. Hauksbee used the design of the electric charge generated from Otto von Guericke and applied vacuum, while adding charge to the ball in the center of the vacuum bulb, which resulted in the generation of a glow of light, resembling Saint Elmo's Fire. Gas discharge tubes over the next centuries evolved in neon lamp, mercury vapor lamps, and the fluorescent light.
1733	Charles François de Cisternay du Fay (1698–1739)	Discovery of a different electric charge, opposite to that of the recognized electron, such as the result of rubbing glass with silk, producing a positive charge, however not recognized as such by Charles du Fay just yet. Charles du Fay described the two opposing charge types as “vitreous” and “resinous,” respectively.
1745	Pieter van Musschenbroek (1692–1761) and Ewald Georg von Kleist (1700–1748)	Documented collection of electric charge (storage of static electricity) by means of the “Leyden Jar,” performed at the university in the city Leiden of the Netherlands.
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current.”
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days
1791	Luigi Aloisio Galvani (737–1798)	Discovery of bioelectricity, the preamble of the discovery of the actionpotential. Introduction of the galvanometer, the forerunner of the voltmeter.
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery; voltaic pile.
1821	Michael Faraday (1791–1867)	Discovery of electromagnetic rotation, leading to his law on electromagnetic induction in 1831. Meanwhile, in 1923 Michael Faraday experimentally verified the concept of refrigeration, introduced based on the work of John Dalton (1766–1844) in 1802 and William Cullen (1710–1790) in 1756.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Refrigerator for general public.
1825	William Sturgeon (1783–1878)	First documented design and application of the electromagnet. William Sturgeon also invented the first operational electric motor in 1832, operating on direct current (DC).
1827	George Simon Ohm (1789–1854)	Description of the linearly proportional relationship between voltage and current, introducing the resistance concept: Ohm's law.
1831	Michael Faraday (1791–1867) and Joseph Henry (1797–1878)	Law of electric induction, leading to the development of the electric generator, where a changing magnetic field induces an electromotive force (EMF), or known as electrical potential.
1833	Michael Faraday (1791–1867)	Recognition of the changes in resistance for materials when exposed to heat, providing the first introduction to the concept of semiconductor properties.
1839	Alexandre-Edmond Becquerel (1820–1891)	Description of the photovoltaic effect, which is different in principle from the photoelectric effect. When light is incident upon the surface of a material (metal or semiconductor), the electrons that reside in the valence band of certain elements of the semiconductor mixture or single metal absorb the electromagnetic energy and are raised to the conduction band (excited) and become free electrons, producing an electromotive force (EMF), yielding an electrical current. The photoelectric effect provided a step further in the recognition of the semiconductor concept, described in <i>Les Comptes Rendus de l'Academie des Sciences</i> . In contrast, the photoelectric effect describes the release of free electrons into free space, compared to conduction under photovoltaic effect. Alexandre-Edmond Becquerel was the father of Antoine Henri Becquerel (1852–1908), the prime discoverer of several fundamental radioactivity features. The photovoltaic effect led to the development of solar cells for the generation of electricity for personal consumption on a large scale.
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential, a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1873	James Clerk Maxwell (1831–1879)	Theory of electromagnetic radiation: <i>A Treatise on Electricity and Magnetism</i> . James Maxwell made use of the prior work by Wilhelm Eduard Weber (1804–1891) and Johann Carl Friedrich Gauss {Gauß} (1777–1855)

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1873	Willoughby Smith (1828–1891)	First formal introduction to semiconductor materials. This was followed by the work of Karl Ferdinand Braun (1850–1918) in 1874 and Sir Franz Arthur Friedrich Schuster (1851–1934), also in 1874.
1874	Karl Ferdinand Braun (1850–1918)	Discovery that joining two materials with different electrical properties (metal vs. semiconductor) acts as a rectifier under certain conditions. This paved the way for the development of diodes and transistors when semiconductor materials became more manageable, and more manufacturable.
1878	Edwin Herbert Hall (1855–1938)	Discovery of the Hall effect: the deflection of electric charge flowing under the influence of an applied magnetic field. The Hall effect was instrumental in the evolution of the diode and in particular the transistor, using semiconductor junctions.
1878	Thomas Alva Edison (1847–1931)	This development of the incandescent light bulb. In 1883, Edison published the discovery of the emission of “electrons” (not known in that sense at that time yet) by a hot wire in an electrical circuit; “Edison effect.” The electron itself was recognized in 1897 by Joseph John Thomson (1856–1940).
1878	William Edward Sawyer (1850–1883)	Contributed to the development of the incandescent light bulb. There were several conflict on ownership to the right (patents) between William Sawyer and Thomas Edison (1847–1931).
1880	Johannes Diderik van der Waals (1837–1923)	Description of the covalent bond. Van der Waals equation.
1882	Thomas Alva Edison (1847–1931)	First commercial power plant serving Lower Manhattan, New York.
1883	Charles Fritts (1850–1903)	First solid-state photovoltaic cell created by coating the semiconductor material selenium with a thin layer of gold to form Schottky barrier junctions, based on the Fermi levels of the respective materials in contact, leading to the generation of electrical potential and electrical current under direct illumination by visible light. The concept device was only approximately 1% efficient, in comparison to current day better than 44%, and still increasing.
1885	George Westinghouse, Jr. (1846–1914)	Electric power distribution network development. George Westinghouse also invented what is known as air brakes (1869) drawing vacuum on a piston to reduce the revolutions of the crack axle, similar principles still apply to air brakes on large trucks.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1887	Heinrich Rudolf Hertz (1857–1894)	Radar development. Detection of electromagnetic radiation (radio waves). Heinrich Hertz also discovered that certain metal plates will release electrons (into free space) when exposed to light, specifically ultraviolet light: photoelectric effect. This concept was elaborated on by Albert Einstein (1879–1955) in 1905.
1893	Nikola Tesla (Serbian-Cyrillic: Никола Тесла; 1856–1943)	First alternating current (AC) electromotor. Nikola Tesla performed high voltage experiments, geared to induction, in Colorado and New York state. Nikola Tesla made significant contributions to the full complement of alternating current electrical device designs. Tesla also successfully experimented in remote control operations, as well as wireless communications. Nikola Tesla is most known for his extravagant experiments on wireless energy transmission, concerning significant voltage levels and current loads. The unit for magnetic flux was named after him in 1960 by General Conference on Weights and Measures, the Tesla. In 1888 Nikola Tesla demonstrated the functional polyphase brushless induction motor.
1893	Pieter Zeeman (1865–1943)	Description of the Zeeman effect: spectral line split under the influence of an applied static magnetic field (in contrast to the Stark effect, which was due to an applied electric field). Additional contributions were made by Hendrik Antoon Lorentz (1853–1928).
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.
1897	Marchese Guglielmo Giovanni Maria Marconi, 1st Marquis of Marconi (1874–1937)	Introduction of wireless communications (radio telegraphy) and radio.
1898	Oliver Heaviside (1850–1925)	Description of the force on a point charge as the result of both an external magnetic and electric field; commonly known as the Lorentz force. James Clerk Maxwell (1831–1879) described a similar principle in a paper in 1855. The work of Hendrik Antoon Lorentz (1853–1928) refined the concept, hence the association of his name.
1898	Antoine Henri Becquerel (1852–1908)	Introduction of units for radioactivity radiation. Collaborator with Manya (Marie) Skłodowska Curie (1867–1934). Henri Becquerel, Marie Curie, and Pierre Curie shared the Nobel Prize in Physics for their radioactivity discoveries in 1903.
1900	Max Karl Ernst Ludwig Planck (1858–1947)	Inception of quantum mechanics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1904	Sir John Ambrose Fleming (1849–1945)	Introduction of the vacuum tube as an electronic mechanism, either performing as a diode, transistor, or even working in the function of an operational amplifier. Student of James Clerk Maxwell (1831–1879).
1905	Albert Einstein (1879–1955)	Theoretical description of the photoelectro effect: emission of electrons from a metal exposed to light. the Einstein theory was confirmed by Robert Andrews Millikan (1868–1953) in 1914. The discovery of the ramifications of the photoelectric effect further fueled the development of the concept of quantum physics. Additional theoretical concepts introduced by Albert Einstein around that time are the theory of special relativity: Relationship between space and time—(1) the laws of physics are invariant in any and all inertial systems, based on a nonaccelerating frame of reference configuration; (2) the speed of light in vacuum is identical to all observers, regardless of the motion of the frame of reference for the light source. The theory is “special” since it applies to the special case of inertial reference frames.
1907	Captain Henry Joseph Round (1881–1966)	Formal introduction of the electroluminescence concept. This would eventually led to the production of light emitting diodes, after the work by Oleg Vladimirovich Losev (1903–1942) in 1927, but not produced until 1962. Henry Round worked as an assistant to Guglielmo Marconi, 1st Marquis of Marconi (1874–1937)
1913	Johannes Stark (1874–1957)	Stark effect: spectral line split under the influence of an applied static electric field (in contrast to the Zeeman effect, which was due to an applied magnetic field).
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model, supporting the fundamental understanding of the p-type and n-type semiconductor principles and the general mode of conduction for valence electrons.
1915	Walter Hermann Schottky (1886–1976)	Development of the basic principles of electron layers resulting from his work on vacuum tubes, which principles also applies to the semiconductor barriers between n-doped and p-doped semiconductor media. The concepts that were introduced included the Schottky barrier, and the Schottky diode.
1916	Gilbert Newton Lewis (1875–1946)	Description of the shell filling for atomic electrons, and the related concept of valence electrons, next to the covalent chemical bond.
1926	Erwin Schrödinger (1887–1961)	Quantum mechanical wave equivalence, wave theory for atomic and nuclear energy configurations.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1925	Julius Edgar Lilienfeld (1882–1963)	First publication of the field-effect transistor concept (applicable to semiconductor media), but not practical for production. The concept was refined in 1938 by Rudolf Hilsch (1903–1972) and Robert Wichard Pohl (1884–1976), providing the solid-state (semiconductor; in contrast to the vacuum tube design in place at the time) amplifier. In 1931 Julius Lilienfeld also introduced the electrolytic capacitor.
1927	Werner Karl Heisenberg (1901–1976)	Uncertainty principle; impossibility to know both the location and the momentum (energy) of a system with absolute accuracy simultaneously. This also removed the causality aspect from events, and substitutes probabilistic distributions.
1927	Oleg Vladimirovich Losev [Russian: Олѣг Влади́мирович Ло́сев] (1903–1942)	Development of the light emitting diode (LED). However, the LED was not manufactured until 1962.
1928	Felix Bloch (1905–1983)	Description of the migration process of electrons in an atomic lattice structure. The electron transport formed what Felix Bloch referred to as a wave process, now referenced as Bloch waves. The wave process (i.e., wavelength) directly corresponds to the periodic nature of the lattice structure, in particular for a crystal.
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine, generating electricity based on induction under wind-powered rotation.
1948	Julian Schwinger (1916–1994), Richard Phillips Feynman (1918–1988), and Sin-Itiro Tomonaga (1906–1979)	Quantum electrodynamics and quantum field theory. Supporting the development of next-generation central processing units (CPUs) for computational applications (computer).
1950	John Alexander Hopps (1919–1998)	Introduction of the “portable” (~44 kg) cardiac pacemaker, based on the earlier work by Mark Lidwell (1878–1969) and Edgar Harold Booth (1893–1963) in 1926. This led, with the development of microprocessors, to the first implantable pacemaker in 1958 by William Chardack (1919–2011) and Wilson Greatbatch (1919–2011).
1957	Jack St. Clair Kilby (1923–2005)	Introduction of the integrated circuit (IC)—chip.
1969	Gordon Earle Moore (1929–), Marcian Edward “Ted” Hoff (1937–) and Federico Faggin (1941–)	Introduction of the microchip/microprocessor/CPU (central processing unit). Gordon Moore is one of the founders of the Intel Corporation. Gordon Moore also introduced a principle known as Moore’s law: the exponential increase of component density on a integrated circuit wafer with respect to years of development.

Energy

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
13.8 billion years BC	Georges Henri Joseph Édouard Lemaître (1894–1966) and Edwin Powell Hubble (1889–1953)	“The Big Bang”; in 1927 the expanding universe was recognized.
350 BC	Aristotle (384 BC–322 BC)	The word “energy” has the Greek origin “ <i>Enérgeia</i> ” [Greek: <i>ἐνέργεια</i>], which was documented by Aristotle, “ <i>Enérgeia</i> ” does not translate directly into English, the meaning resembles: “being at work.”
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca 80 BC–10 BC)	Architectural designs that harness the solar energy.
550	Ireland	Introduction of tidal mills. Work performed by machine based on the flow of water resulting from the changing tides in ocean and seawater level as well as resulting from the flow of rivers based on elevation (waterwheel).
650	Persia	First recorded use of wind mills and wind energy in the Persian Empire.
800	Persia, the Netherlands; detailed scientific documentation by Simon Stevin (1548–1620)	Wind energy used to pump water, windmill water pump: windpump. Other use of the windmill was in manufacturing, for example, papermaking, cloth fabrication, wheat processing, and later for the generation of electricity.
1500	Leonardo da Vinci (1452–1519)	Energy conservation principle illustrated (“described”) by several of the machines designed by Leonardo da Vinci.
ca. 1632	Galileo Galilei (1564–1642)	Account of friction in the energy exchange with respect to work. Additional work on energy conservation was described in the <i>Dialogue Concerning the Two Chief World Systems</i> , representing the Galilean invariance.
ca. 1687	Sir Isaac Newton (1643–1727)	Newton’s statement on “conservation of energy”: “Energy is not lost or destroyed, it is merely transferred from on party to the next.”
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine.
1712	Thomas Newcomen (1664–1729) and John Calley (1663–1717)	Construction of an “atmospheric” steam engine.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1776	Luigi Galvani (1737–1789)	Biomedical connection to electricity and development of a mechanism to measure electrical energy, respectively, electrochemical potential.
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge was still an elusive concept in those days.
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery.
1820	Pierre Louis Dulong (1785–1838) and Alexis-Thérèse Petit (1791–1820)	Dulong and Petit law of specific heats.
1821	Thomas Johann Seebeck (1770–1831) and in 1834 Jean Charles Athanase Peltier (1785–1845) [greater detail]	Thermoelectric effect.
1827	Benoît Fourneyron (1802–1867)	First water turbine.
1831	Michael Faraday (1791–1867) and Joseph Henry (1797–1878)	Law of induction, leading to the development of the electric generator.
1845	James Prescott Joule (1818– 1889)	Energy definition; mechanical equivalence of heat.
1839	Sir William Robert Grove (1811–1896)	Introduction of the first hydrogen–oxygen fuel cell.
1861	Augustin Mouchot (1825–1911)	Presentation of the use of solar energy as a source for personal energy consumption.
1865	August Joseph Ignaz Toepler (1836–1912)	Electrostatic charge generation.
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential, a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1876	Alexander Graham Bell (1847–1922)	Introduction of the telephone. Other efforts involved hydrofoils and aeronautics.
1877	Thomas Edison (1847–1931)	Introduction of the phonograph and telegraph machine and the electric light bulb.
1880	Johannes Diderik van der Waals (1837–1923)	Description of chemical bonding energy. Van der Waals equation.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1880	James Wimshurst (1832–1903)	Electrostatic charge generation.
1888	Inspired by Michael Faraday (1791–1867)	First electric power generator by means of induction based on revolutions provided by a bush postmill, wind energy.
1892	Sir John Ambrose Fleming (1849–1945)	Electrical transformer theory and communications. Introduction of the thermionic valve, electronic device.
1893	Nikola Tesla (1856–1943)	Design of modern alternating current technology. Worked for Thomas Edison (1847–1931) on telephony. On his own, he developed the induction motor design. Tesla also worked on X-ray imaging and radio transmission.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.
1900	Max Karl Ernst Ludwig Planck (1858–1947) and James Clerk Maxwell (1831–1879)	Formal description of the photon and the energy associated with the electromagnetic wave.
1904	Piero Ginori Conti, Prince of Trevignano, (1865–1939)	Geothermal electric generator.
1914	Niels Henrik David Bohr (1885–1962)	Description of the atomic energy layer model; hydrogen (Bohr atomic model).
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.
1923	Arthur Holly Compton (1892–1962)	Description of the deflection of photons by a nucleus: Compton effect.
1927	Werner Karl Heisenberg (1901–1976)	Quantum uncertainty principle.
1927	Paul Adrien Maurice Dirac (1902–1984)	Description of antimatter.
1929	Robert Jemison van de Graaff (1902–1967)	Electrostatic charge generation.
1931	Carl David Anderson (1905–1991)	Discovery of the positron, anti-particle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.
1932	Sir James Chadwick (1891–1974)	Discovery of the neutron.
1934	Hideki Yukawa [湯川秀樹], (1907–1981)	Introduction of mesons and the concept of antimatter.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1937	Carl David Anderson (1905–1991), Seth Henry Neddermeyer (1907–1988), Jabez Curry Street (1906–1989) and Edward C. Stevenson (1937–)	Confirmation of the existence of the meson, and muon.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962); Enrico Fermi (1901–1954); Eugene Wigner (1902–1995), and dozens more.
1947	William Webster Hansen (1909–1949)	Linear accelerator installation at Stanford University, California.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model for atomic nuclei.
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.
1958	Stanley Mandelstam (1928–2016)	Introduction of Mandelstam variables associated with the concept of “crossing symmetry,” defining numerical quantities which encode the energy, momentum, and scattering angles of particles in a deflection process described in a Lorentz invariant fashion.
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович Бенедиктович Мигдаль] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.
1960	George Irving Bell (1926–2000)	Fundamental contributor to the evolution of the nuclear energy program.
1961	Murray Gell-Mann (1929–)	Description of elementary particles, eight-fold way of defining “strangeness” for the quark.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Николай Геннадиевич Басов] (1922–2001) and Aleksandr Mikhailovich Prokhorov [Александр Михайлович Прохоров] (1916–2002)	Quantum electronics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1972	Stephen Hawking (1942–), Jacob Bekenstein (1947–2015)	Thermodynamics of black holes.
1978		Discovery of the “gluon” with the assistance of the Pluto, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1983	Collider detector at Fermilab	World’s first and at the time highest-energy particle accelerator, colliding antiprotons and protons propelled to center-of-mass energy reaching 2 TeV.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland. The Large Hadron Collider construction started in 1998 and produces particle acceleration with respective energy levels for protons at up to 4 teraelectronvolts (0.64 microjoules), or lead nuclei: 2.76 TeV per nucleon or 574 TeV per nucleus. The proton energy level was increased to 6.5 TeV in 2015.

Engineering

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1.8 million years BC		Use of stone tools, axe, scraper, and hammer.
200000 BC		<i>Homo sapiens</i> .
25000 BC		Ceramics; baked clay.
9000 BC		Bow and arrow.
6000 BC–2000 BC	Stone Age	Mechanical labor and tool fabrication.
c. 6000 BC	Egypt	First recorded drawings of rudimentary water crafts.
c. 4000 BC	Eastern Europe, Arabic nations, Mesopotamia (specifically: Sumeria/ Sumer)	First recorded drawing of craft with rudimentary wheels. Most prominent: use of pieces/slice of tree trunk as wheel, attached to an axle (Ljubljana, Slovenia).
4000 BC	Mesopotamia and Egypt	Documented recording of the construction of shelter, abandoning the nomadic structure.
4000 BC		First documented use of lime-based mortar. Prior to this most building assembly relied on clay or mud as the cohesive element to connect stone blocks together.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
c. 3500 BC		First documented installation of sewer systems, primarily run-off.
c. 3300 BC	Egypt	Drawings of sail boats.
3300 BC–1000 BC	Bronze Age	Smelting and forging of soft metals using low heat: copper, tin, and gold. This age also introduces the written documentation.
2700 BC–2500 BC	Egypt	Construction of pyramids, requiring advanced mechanical engineering efforts and architectural design (civil engineering).
1600 BC	Babylonian empire	Use of water clocks for time keeping.
c. 1000 BC	Qanat aqueduct; Persia	Water supply over a length greater than 71 km, and potential relation with sewer as a secondary use for liquid transport as part of the civil engineering efforts.
1000 BC–700 AD	Iron Age	Higher heat requirements and more detailed tool manufacturing, introducing scientific and engineering challenges. Historical tracking of processes and developments and philosophies. Introduction of complicated mechanisms and requiring detailed analytical thinking.
c. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Introduction of metrology, measurements of the height of pyramids with proposed standards. Introduced the concept of logic proof.
520 BC	Pythagoras (571 BC–495 BC)	Pythagorean theorem for a triangle.
430 BC	Socrates (469 BC–399 BC)	Scholar and educator, introducing analytical thinking.
c. 360 BC	Plato (427 BC–347 BC)	Student of Socrates (469 BC–399 BC). Founder of the principles for modern philosophy and science. The Plato school of teaching included, but not limited to astronomy, biology, mathematics, philosophy, and political theory.
300 BC	Roman empire	Waterwheel used for drainage next to perform work.
350 BC	Aristotle (384 BC–322 BC)	Introduction of modern physical science concepts (natural philosophy) and logic (including deductive reasoning). Aristotle's attention in teaching ranged from anatomy, to astronomy (promoting the wrong concept of a geocentric system for earth and the sun), embryology, geography, geology, meteorology, including physics as well as zoology.
c. 310 BC	Euclid (c. 350 BC–c. 275 BC)	Euclidean geometry; still valid for classical mechanics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
c. 300 BC	Zhou Bi Suan Jing (周髀算經) (Zhou Dynasty (1046 BC–256 BC))	Documented proof of the Pythagorean theorem, shortly after the “western” proof by Pythagoras (571 BC–495 BC)
c. 250 BC	Archimedes (287 BC–212 BC)	Revealed the properties that define buoyancy. Developed calculus and algebra and created a system for “abbreviating” large numbers by means of what we now consider exponential expressions. Archimedes also described the mechanics of a level, defining torque. Still primarily statics.
c. 280 BC–247 BC	Alexandria, Egypt	Lighthouse of Alexandria. The city of Alexandria was erected by Alexander the Great of Macedon [Greek: Ἀλέξανδρος ὁ Μέγας] (356 BC–323 BC) in 332 BC. The lighthouse was one of the tallest man-made architectural structures for many centuries and was partially destroyed as a result of a series of earthquakes over the period 956–1323.
c. 220 BC	China	Civil engineering effort of the architectural and mechanical design and construction of the Great Wall, Ming Dynasty. As mortar the engineers used sticky rice
142 BC	Rome, Italy	Oldest known arch bridge, made from stone.
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca 80 BC–10 BC)	Roman engineering architect and civil engineer. Vitruvius served under Gaius Julius Caesar (100 BC–44 BC). In the army position, he was also charged with the care of the infirmed, where he used early biomedical engineering approaches for novel diagnosis and treatment. Vitruvius provided a detailed description of the preparation and use of lime-based gypsum mortar for construction use. The Romans added volcanic ash to make the concrete mixture resistant to water, and used it in the construction of aqueducts; lime itself will not harden or will decay when continuously exposed to water. Description of the use of a waterwheel to measure the distance traveled by a ship (odometer).
10 BC	Strabo (64 BC–24 AD)	Description of the use of a waterwheel-powered mill; Turkey/Egypt/Mesopotamian empire.
62	Hero of Alexandria [ῥωνό Ἀλεξανδρεὺς], (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. A set of two books: <i>The Pneumatica</i> describes mechanical devices worked by air, steam, or water pressure. Also known as Heron of Alexandria. He invented a steam-powered engine called the “Æolipile.”
105	Apollodorus of Damascus (2nd century)	Architect and construction engineer for the longest known ancient technology arch bridge over the river Danube: Trajan Bridge. The bridge was created to facilitate the transport of troops across Europe.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
120	Claudius Ptolemy {Ptolemaeus} [Πτολεμαῖος] (90–168)	Geographic recordings of a significant part of the Islamic and Western world (i.e., Roman and Persian Empire), living in Egypt, as a Roman with Greek education. His cartography extended all the way out, including parts of China (discovered in 15th century). He specifically developed arithmetical techniques for calculating astronomical phenomena, under the teachings of Babylonian astronomers. Also known as: بطليموس (Batlamyus; Arabic).
132	Zhang Heng (78–139)	First known construction and use of a seismograph, Han Dynasty.
400	Roman empire	Description of the use of a waterwheel for propulsion of a boat by means of an ox: paddle-wheel (publication <i>De Rebus Bellicis</i>).
644		Wind-powered devices developed by the Persians.
900–1200	Mexico, central America	Construction of temples which apparently have a close correlation to astronomical observations. Civil engineering.
1176	France	Mechanical clock tower: “horologe”; presumably powered by running water.
1430	Philip the Good, Duke of Burgundy (1396–1467)	Spring-driven clock.
1450	Machu Picchu, Peru	Construction of an Incan citadel in the Andes mountains. No mortar (no cement) was used in the assembly process.
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man,” involved in all aspects of cultural evolution, science, engineering, politics, and art. Da Vinci designed a water-powered gyroscopic compass.
1510	Peter Henlein (1485–1542)	Spring-driven time-keeping device: clock; “Nuremberg-egg” pocket watch.
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.
c. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re) introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei recognized that motion would be uninterrupted if there were no constraints; that is, no friction.
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits.
1632	Evangelista Torricelli (1608–1647)	Introduction of the barometer; essential in weather prediction; meteorology.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1650	Blaise Pascal (1623–1662)	Pascal's law, pressure in a container applies an equal force on all surface of the enclosure.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas as a potential “shock-absorber,” acting similar to a spring.
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” powered by gun powder. Huygens introduced several concept of mechanical engineering and described the mechanism of shock waves. Christiaan Huygens is most known for his lens manufacturing and optical design of telescopes. The mathematical efforts of Christiaan Huygens in probability theory were far advanced and he collaborated with the mathematician Pierre de Fermat (1601–1665) from France.
1679	Denis Papin (1647–c. 1712)	Pressure and thermodynamic and mechanical impacts.
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring, linearly proportional to the compression length: spring constant.
c. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced three laws of motion dynamics: (1) an object remains at rest, or move in steady-state velocity, unless an externally applied force persuades it to change the status quo; (2) the sum of the forces acting on a body will change the motion (i.e., acceleration) of that body in a linear proportion and in the direction of the resultant of these forces, (3) for every action there is an equal but opposite reaction. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action–reaction, gravitational acceleration, inertia, and force with respect to acceleration. Introduction of the three laws of motion.
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine; using information obtained by Denis Papin (1647–c. 1712).
1705	Edmond Halley (1656–1742)	Discovery of, and mathematical description of the trajectory for “Halley's comet.”
1712	Thomas Newcomen (1664–1729)	Construction of a “atmospheric” steam engine.
1714	Brook Taylor (1685–1731)	Fundamental frequency of vibration; string. Additional work on pure mathematics: Taylor series.
1727	Leonard Euler (1707–1783)	Introduction of the concept of the elastic modulus, experimentally verified by Giordano Riccati (1709–1790) in 1782 and mathematically introduced by Thomas Young (1773–1829) in 1807, now known as Young's modulus.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1732	Anders Celsius (1701–1744)	Thermometer scale calibration based on pure water phases.
1733	Daniel Bernoulli (1700–1782)	Acoustics, mechanical vibrations, and fluid-dynamic principles introduced. Definition of the fundamental frequency and higher harmonics, with supporting elaborate mathematical analysis (solutions to differential equations).
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases.
1743	Jean-Baptiste le Rond d'Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> .
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current.”
1756	John Smeaton (1724–1792)	Introduction of pozzolans (pozzolanic earth) mixed in with mortar to provide a water-resistant cement mortar.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1762	Joseph Black (1728–1799)	Realization of the concept of latent heat.
1760–1820		Industrial Revolution.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days. Introduction to the scientific aspects of electrical engineering.
1783	Antoine Laurent de Lavoisier (1743–1794)	Discovery of oxygen and the chemical impact, oxidation. Scientific approach to the chemical engineering aspects of phenomena, both natural and artificial.
1783	Joseph-Michel Montgolfier (1740–1810) and Jacques-Étienne Montgolfier (1745–1799)	Hot-air balloon; buoyancy.
1785	Jacques Alexandre César Charles (1746–1823)	Charles's law, expansion of gases.
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery. The introduction of the electrical engineering aspect of technology.
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1807	Thomas Young (1773–1829)	Formal introduction of the Young's modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783).
1821	Michael Faraday (1791–1867)	Discovery of electromagnetic rotation, leading to his law on electromagnetic induction in 1831. Meanwhile, in 1923 Michael Faraday experimentally verified the concept of refrigeration, introduced based on the work of John Dalton (1766–1844) in 1802 and William Cullen (1710–1790) in 1756.
1824	Joseph Aspdin (1778–1855)	Introduction of portland cement; mixture of limestone, clay, and a blend of minerals in carefully controlled proportions. The constituents of the Portland cement were calcined (thermal treatment process used for decomposition or purification) and ground into a fine aggregate of particles. portland cement versus primarily produced and distributed from within Europe.
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Refrigerator for general public.
1827	Benoît Fourneyron (1802–1867)	First water turbine.
1831	Michael Faraday (1791–1867) and Joseph Henry (1797–1878)	Law of induction, leading to the development of the electric generator.
1840	Jean Léonard Marie Poiseuille (1799–1869) and Gotthilf Heinrich Ludwig Hagen (1797–1884)	Pressure drop for incompressible fluids with respect to laminar flow.
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin.
1851	Jean Bernard Léon Foucault (1819–1868)	Foucault pendulum, illustrating the impact of the earth's rotation on motion.
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule-Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid, or liquid. Sometimes also found as the Joule-Kelvin effect.
1854	Robert Wilhelm Eberhard Bunsen (1811–1899)	Bunsen burner.
1859	James Clerk Maxwell (1831–1879)	Description of the distribution law of molecular velocities.
1861	Augustin Mouchot (1825–1911)	Presentation of the use of solar energy as a source for personal energy consumption.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1866	Ludwig Eduard Boltzmann (1844–1906) and Josiah Willard Gibbs (1839–1903)	Statistical mechanics, correlating energy, and heat, to the movement (velocity).
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential: a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1873	James Clerk Maxwell (1831–1879)	Theory of electromagnetic radiation: <i>Treatise on Electricity and Magnetism</i> . James Maxwell made use of the prior work by Wilhelm Eduard Weber (1804–1891) and Johann Carl Friedrich Gauss {Gauß} (1777–1855).
1875	Siegfried Samuel Marcus (1831–1898)	Siegfried Marcus automobile, powered by an internal combustion engine; Vienna, Austria. Predecessor to the “modern” automobile. In 1883 Siegfried Marcus received a patent on a ignition magnet (ignition magneto), now know as a distributor, providing ignition electrical discharges to then respective cylinders in the correct order and on-time at the correct cylinder position, just a few degrees before the piston connecting-rod stretches to the top of the cylinder.
1880	Johannes Diderik van der Waals (1837–1923)	Description of the covalent bond. Van der Waals equation.
1883	John Joseph Montgomery (1858–1911)	Montgomery glider; first piloted flight with an aircraft “heavier than air” (vs. the hot-air balloon) transporting human passengers. Montgomery fell victim to his own ingenuity and died in a crash of one of his glider designs.
1887	Heinrich Rudolf Hertz (1857–1894)	Radar development. Detection of electromagnetic radiation (radio waves). Heinrich Hertz also discovered that certain metal plates will generate electricity when exposed to light: photoelectric effect.
1891		Manitou Springs, Colorado: Cog railway leading up to the top of Pikes Peak of the Rocky Mountains, mountain ridge.
1894	Max Karl Ernst Ludwig Planck, (1858–1947)	Black-body radiation.
1895	Folsom, California	First operational hydroelectric power plant.
1897	Guglielmo Marconi, 1st Marquis of Marconi (1874–1937)	Introduction of wireless communications and radio.
1900	Anne Rainsford French Bush (1878–1962)	First licensed female steam engineer in the United States of America.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1900	Ferdinand Adolf Heinrich August Graf von Zeppelin (1838–1917)	Successful dirigible, gas-filled air floatation device with propulsion.
1925	Karl von Terzaghi (1883–1963)	Foundation of geotechnical engineering, considered a subsection of civil engineering, linking structural design to the soil foundation mechanical conditions. Publication: <i>Erdbaumechanik</i> . One specific example of the influence of Karl von Terzaghi is the maximum slope (abutment; 90 degrees being vertical) for a dam that will hold under its own weight, such as found in ridges on which railways are raised above the topography of the terrain, or the design and construction of levees. For sand, the slope is roughly 45 degrees, whereas for bricks or clay the slope can be stable up to 60°.
1926	Mark Cowley Lidwell (1878–1969) and Edgar Harold Booth (1893–1963)	Rudimentary, but effective, external cardiac pacemaker design.
1930	Richard Buckminster Fuller (1895–1983)	Mechanical engineering and engineering architecture, as well as chemistry; Bucky-ball, multipoint connections in both chemical structures and mechanical structures.
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.
1937–1959	Chester Floyd Carlson (1906–1968)	Photocopy machine, patented in 1942. The first photocopier was offered for sale by the Haloid company in 1959, later renamed Xerox.
1950	John Alexander Hopps, (1919–1998)	Introduction of the “portable” (45 kg) cardiac pacemaker, based on the earlier work by Mark Lidwell (1878–1969) and Edgar Harold Booth (1893–1963) in 1926. This led, with the development of microprocessors, to the first implantable pacemaker in by William Chardack (1919–2011) and Wilson Greatbatch (1919–2011).
1956	Paul Winchell {Wilchinsky} (1922–2005)	Artificial heart (Jarvik 7).
1969	NASA	First lunar landing; Apollo 11: Neil Armstrong (1930–2012), Michael Collins (1930–) [commander of lunar orbiter module], and Buzz Aldrin {Edwin Eugene Aldrin Jr} (1930–).
1979	K.V. Hall, R.L. Kaster, A. Wøien	Application of an in vivo artificial bileaflet replacement heart valve.

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Fluid Dynamics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 3300 BC	Egypt	Drawings of sailboat.
ca. 2000 BC	Egypt; India	Irrigation systems.
350 BC	Aristotle (384 BC–322 BC)	Founder of the Lyceum school of analytical thinking in Macedonia. Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle supposed an external force (acting during flight) perpetuating the projectile motion of a ballistic object.
144 BC	Italy	Construction of aqueducts.
1010	Eilmer of Malmesbury, 11th century Benedictine monk	First documented successful flight, performed with a wooden frame lined with parchment, traveling approximately 200 meter in free fall from a 18 meter elevation.
1206	Al-Jazari (1136–1206) [Turkey]; Badi' al-Zaman Abū al-'Izz ibn Ismā'il ibn al-Razāz al-Jazarī (بْنُ الْعِزِّ أَبُو الزَّمَانِ بَدِيعُ)	Publication of <i>Book of Knowledge of Ingenious Mechanical Devices</i> . Description of mechanical devices and mechanism of action.
1245	Thomas Aquinas (1225–1274)	Reformulation of the dynamic concepts of Aristotle (384 BC–322 BC).
1500	Leonardo da Vinci (1452–1519)	Description of early friction concepts, and derivation of the conservation of mass equation for one-dimensional flow. Documented descriptions of wave phenomena, fluid jets, hydraulic pumps, eddy current formation, and low-drag flow as well as high-drag (turbulent flow around an object being pulled through a fluid) flow.
1586	Galileo Galilei (1564–1642)	Investigation on the aspect of drag (friction) on falling objects. The Galilei number is the ratio of the gravitational forces over the viscous forces, yielding a dimensionless number; however, the number was not introduced by Galileo Galilei.
ca. 1660	Edme Mariotte (1620–1684)	First wind tunnel construction to test some of the concepts introduced by Leonardo da Vinci (1452–1519), and his own observations and curiosity.
ca. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced the three laws of motion. His additional contributions in fluid dynamics describe the law of viscosity for linear fluids. Linear fluids (idealized fluid) are referred to as Newtonian fluids.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1699	Guillaume Amontons (1663–1705)	Formal introduction of the concept of friction, based on the rudimentary introduction by Leonardo da Vinci (1452–1519).
1732	Henry de Pitot (1695–1771)	Investigation of the velocity of flow as a function of depth, disproving the leading theory that flow velocity increases with depth. Original design of the “Pitot tube” used to measure the flow velocity.
1738	Daniel Bernoulli (1700–1782)	Demonstration of the Bernoulli’s principle: relationship between flow velocity and pressure, for inviscid flow. The Bernoulli principle defines the behavior of flight with respect to lift on the airplane wing, as well as the mixing of fluids (combustible and air for a carburetor. Published in <i>Hydrodynamica</i> .
1743	Jean-Baptiste le Rond d’Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> . Mathematical description of frictionless flow.
1750	Leonard Euler (1707–1783)	Introduction of the coefficients representing kinetic and static friction; creation of what we consider the Bernoulli equation, differential flow formulation as well as the integral form.
1765	Antoine de Chézy (1718–1798)	Description of steady-state turbulent flow in an open channel, linking the average velocity to the radius of the channel and the depth of the flow.
1781	Charles-Augustin de Coulomb (1736–1806)	Verification of the friction principles that were introduced by Guillaume Amontons (1663–1705).
1797	Giovanni Battista Venturi (1746–1822)	A tube with two tapered ends joining at the narrow ends provides a drop in pressure. This “ventury” can provide suction when a hole is placed in this narrow passage.
1811	Augustin Louis de Cauchy (1789–1857)	Mathematical description of wave phenomena in elastic media and elastic membranes. Cauchy also introduced the concept and definition for stress, which are complementary to those of Siméon Denis Poisson (1781–1840).
1820	Gotthilf Heinrich Ludwig Hagen (1797–1884)	Theoretical design for hydraulic engineering projects.
1838	Jean-Louis Léonard Marie Poiseuille (1799–1869)	Introduction of the Hagen–Poiseuille law describing nonturbulent flow through a compliant system (e.g., blood vessels, primarily applicable to smaller diameter vessels), crediting the influence of Gotthilf Heinrich Ludwig Hagen (1797–1884). The flow applies to steady-state conditions for a Newtonian fluid that is incompressible.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1839–1868	Heinrich Gustav Magnus (1802–1870)	Description of the process of absorption of gases in blood (respiration); vapor pressure for evaporated liquids. A projectile spinning object will veer away from the original trajectory: Magnus effect. This applies, for instance, to rotating propellers and pitched baseballs.
1840	Claude-Louis Navier (1785–1836) and George Gabriel Stokes (1819–1903)	Fluid dynamics based on Newton's second law concepts incorporating friction concepts and pressure gradient: Navier–Stokes equations.
1845	Henry Philibert Gaspard Darcy (1803–1858)	Redisign of the Pitot tube, used to measure the local flow velocity. Still in use to measure the speed of flight for airplanes.
1850	Julius Ludwig Weisbach (1806–1871)	Refined the work of Henry Philibert Gaspard Darcy (1803–1858) and wrote a series of physics textbooks. Weisbach studied under Johann Carl Friedrich Gauss (1777–1855).
1861	William Froude (1810–1879)	Applications to ship design, reducing the roll of a ship by means of a keel. The hydrodynamic behavior of the hull of a ship could be gauged based on the Froude number, derived from a set of experimental obtained data points.
1875	Lord Rayleigh (1842–1919) [John Strutt]	Dimensional analysis technique to provide a theoretical approach with regard to diabatic incompressible flow in a system with a constant cross-sectional area, neglecting the heat exchange aspects.
1877	Ernst Waldfried Josef Wenzel Mach (1838–1916)	Study and description of shock waves, introduced the Mach number for travel velocity with respect to the speed of sound. Additional work of Ernst Mach was in interferometry, Doppler effect aspects and acoustics.
1878	Vincen Strouhal (1850–1922)	Introduction of a dimensionless parameter that describes the tail or wing kinematics of swimming and flying animals in addition to flying object with fixed wings (e.g., airplane). The Strouhal number is the ratio of the characteristic length of the object in the flow, multiplied by the frequency of the observed phenomenon (e.g., vortex; flapping wings) in reference to the velocity of the object with respect to the flow of the medium. The Strouhal number is a function of the Reynolds number, also dimensionless.
1883	Osborne Reynolds (1842–1912)	Friction description with respect to fluid dynamics concepts. Introduction of the Reynolds number defining the ratio of inertial force with respect to viscous forces. The Reynolds number provides a method to compare similar flow patterns under different fluid flow situations.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1889	Robert Manning (1816–1897)	Description of the average flow velocity for free-flow pipe flow based on the incline, and the radius of the pipe and fill area of the tube (jointly providing the wetted area, or hydraulic radius): Manning formula.
1895	Diederik Johannes Korteweg (1848–1941) and Gustav de Vries (1866–1934)	Diederik Korteweg and his student Gustav de Vries derived a nonlinear partial differential equation defining the propagation of waves in shallow water. The Korteweg–de Vries (KdV) equation describes the solitary wave described by John Scott Russell (1808–1882). The KdV equation has had an important implications for the development of the mathematical description of solitons.
1899	Jules Henri Poincaré (1854–1912) and Jacques Salomon Hadamard (1865–1963)	Geodesic flow; mathematical description and physical analysis. With further analysis by George David Birkhoff (1884–1944) in 1927.
1904	Ludwig Prandtl (1875–1953)	Description of the boundary layer for viscous flow, formed at the interface with a solid surface.
1905	Orville Wright (1871–1948) and Wilbur Wright (1867–1912)	First sustained flight with a powered fixed-wing aircraft.
1905	Vito Volterra (1860–1940)	Description of plastic deformation of ductile materials, describing the ability of solid materials to deform under tensile stress, using a theory of dislocations. One example is bending a metal coat hanger.
1907	Edgar Buckingham (1867–1940)	Description on the movement of soil moisture (“capillary action”), as well as gas diffusion in soil.
1910	Moritz Weber (1871–1951)	Analysis of multiphase flow at the boundary interface, in principle Weber compared the inertia of the fluid motion to the surface tension at the interface, described by the Weber number.
1915	Paul Richard Heinrich Blasius (1883–1970)	Description of the net force resulting from fluid flow applied to a fixed body submerged in the flow, using a complex velocity potential defining the flow. The solution of the Blasius theorem uses the Cauchy residue theorem (Augustin Louis de Cauchy [1789–1857]). Student of Ludwig Prandtl (1875–1953).
1923	Sir Geoffrey Ingram Taylor (1886–1975)	Combined contributions to fluid dynamics and wave theory, specifically in a convoluted form applied to vortex formation. Specific topics in his research were with respect to flow through porous surfaces and sheet flow. Taylor contributed to the development of the supersonic aircraft, ca. 1946.
1924	Theodore von Kármán (1881–1963)	Introduction of the Kármán vortex street concept. The Kármán vortex can result in resonance effect and Aeolian sound production.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.
1937	Sir Frank Whittle (1907–1996)	Introduction of the jet engine.
1944	Lewis Ferry Moody (1880–1953)	Friction computation and introduction of the Moody chart, plotting the roughness with respect to Reynolds number of flow and the Darcy–Weisbach friction factor defining the surface contact.
1947	Chuck Yeager (1923–)	Breaking of the sound barrier during level flight.
1957	Owen Martin Phillips (1930–2010), respectively John Wilder Miles (1920–2008)	Gravity wave with respect to either water surface (e.g., ocean waves) or wind flow direction (3D) or capillary wave concept. Theoretical description by means of Stokes wave or Airy wave formulation.
1981	Uri Dinnar (1939–2014)	Theoretical description of periodic turbulent and viscous (non-Newtonian) flow, specifically applicable to blood flow in large (compliant) vessels.

General

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
6000 BC–2000 BC	Stone Age	Mechanical labor and tool fabrication.
ca. 6000 BC		First recorded use of floatation devices: boats. This illustrated the Archimedes principle (Archimedes [287 BC–212 BC]), but no documented descriptions on the floatation principles from those days.
ca. 4000 BC		First recorded use of wheel for transportation.
ca. 3000 BC		Traceable use of a potter's wheel used for the construction of crockery.
3300 BC–1000 BC	Bronze Age	Smelting and forging of soft metals using low heat: copper, tin, gold. This age also introduces the written documentation.
1000 BC–700 AD	Iron Age	Higher heat requirements and more detailed tool manufacturing, introducing scientific and engineering challenges. Historical tracking of processes and developments and philosophies. Introduction of complicated mechanisms and requiring detailed analytical thinking.
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Introduction of metrology, measurements of the height of pyramids with proposed standards. Introduced the concept of logic proof.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
430 BC	Socrates (469 BC–399 BC)	Scholar and educator, introducing analytical thinking.
ca. 360 BC	Plato (427 BC–347 BC)	Student of Socrates (469 BC–399 BC). Founder of the principles for modern philosophy and science. The Plato school of teaching included, but not limited to, astronomy, biology, mathematics, philosophy, and political theory.
350 BC	Aristotle (384 BC–322 BC)	Student of Plato (427 BC–347 BC). Founder of the Lyceum school of analytical thinking in Macedonia. Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle hypothesized an external horizontal force (acting during flight) perpetuating the projectile motion of a ballistic object, which is incorrect; only gravity forces the object downward.
ca. 250 BC	Archimedes (287 BC–212 BC)	Revealed the properties that define buoyancy. Developed calculus and algebra and created a system for “abbreviating” large numbers by means of what we now consider exponential expressions.
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca. 80 BC–10 BC)	Roman engineering architect and civil engineer. Vituvius served under Gaius Julius Caesar (100 BC–44 BC). In the army position he was also charged with the care of the infirmed, where he used early biomedical engineering approaches for novel diagnosis and treatment.
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεὺς], (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. A set of two books: <i>The Pneumatica</i> describes mechanical devices that work by air, steam, or water pressure. Also known as Heron of Alexandria. He invented a steam-powered engine called the “Æolipile.”
120	Claudius Ptolemy {Ptolemaeus} [Πτολεμαῖος] (90–168)	Geographic recordings of a significant part of the Islamic and western world (i.e., Roman and Persian Empire), living in Egypt, as a Roman with Greek education. His cartography extended all the way out, including parts of China (discovered in the fifteenth century). He specifically developed arithmetical techniques for calculating astronomical phenomena, under the teachings of Babylonian astronomers. Also known as: بطليموس (Batlaymus; Arabic).
644		Wind-powered devices developed by the Persians.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
771	Karel de Grote (742–815)	General scientific contributions as the ruler of the Netherlands and associated territories (stretching out over France to the Mediterranean and western Germany). Karel de Grote's scientific contributions, including chemical implementations [e.g., crop-growing circulation/alternation] and encouraged teaching of mathematics and scientific problem solving. Karel de Grote encouraged scientific and cultural engagement, during the period of the "Dark Ages (fourth to thirteenth century)" and his time is considered a predate to the "Renaissance" (fourteenth to seventeenth century), named the "Karolinger Renaissance," after Karel (English: Karl).
1500	Leonardo da Vinci (1452–1519)	The preverbal "Renaissance man," involved in all aspects of cultural evolution, science, engineering, politics, and art.
1503	Gregor Reisch (1467–1525)	Detailed outline of the state-of-the-art science and engineering knowledge to date, including human anatomical drawings in the publication <i>Margarita Philosophica</i> . The total works of Gregor Reisch form a series of 12 books compiling an encyclopedia describing topics ranging from Latin grammar, to dialectics, rhetoric, arithmetic, music, geometry, astronomy, physics, natural history, physiology, psychology, and ethics.
1512	Gregorius Reisch (1467–1525)	Introduction of the concept of the theodolite, used for topography and geographic location determination.
1543	Nicolaus Copernicus (1473–1543); Alias of Niclas Koppernigk	Introduction of the heliocentric model for the earth, Sun, and other planets. This follows the statement by the astronomer from Greece: Aristarchus of Samos (ca. 310–ca. 230 BC), made more than 1700 years prior. The scientific observations made by Copernicus were validated by Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.
ca. 1600	William Gilbert (1544–1603)	Experimentalist. Description of magnetism, in his work <i>De magnete, magnetisque corporibus, et de magno magnete tellure</i> . The compass had been in use since 206 BC (Chinese Han Dynasty: 206 BC–220 AD; maybe even earlier, during the Qin Dynasty: 221 BC–207 BC), in the European and Persian area since the thirteenth century.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re) introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei was remanded under house arrest by the Roman Inquisition for his views and teachings where he died after 9 years. This was the trailing end of the Renaissance period.
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits. Descartes also made an illustration of the earth's magnetic field configuration in 1644, in his model the moon and celestial objects participated in the formation of the path of the magnetic field lines. Based on the limited experimental observations available in his time the premise was still not bad.
1632	Evangelista Torricelli (1608–1647)	Introduction of the barometer; essential in weather prediction; meteorology.
1650	Blaise Pascal (1623–1662)	Pascal's law, pressure in a container applies an equal force on all surface of the enclosure.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas as a potential “shock-absorber,” acting similar to a spring.
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” powered by gun powder. Huygens introduced several concept of mechanical engineering and described the mechanism of shock waves. Christiaan Huygens is most known for his lens manufacturing and optical design of telescopes. The mathematical efforts of Christiaan Huygens in probability theory were far advanced and he collaborated with the mathematician Pierre de Fermat (1601–1665) from France.
1679	Denis Papin (1647–ca. 1712)	Pressure and thermodynamic and mechanical impacts.
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring.
ca. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced several laws of motion. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action–reaction, gravitational acceleration, inertia, and force with respect to acceleration. Introduction of the three laws of motion.
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine; using information obtained by Denis Papin (1647–ca. 1712).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1705	Edmond Halley (1656–1742)	Discovery of, and mathematical description of the trajectory for “Halley’s comet.”
1712	Thomas Newcomen (1664–1729)	Construction of a “atmospheric” steam engine.
1714	Brook Taylor (1685–1731)	Fundamental frequency of vibration; string. Additional work on pure mathematics: Taylor series.
1727	Leonard Euler (1707–1783)	Introduction of the concept of the elastic modulus, experimentally verified by Giordano Riccati (1709–1790) in 1782 and mathematically introduced by Thomas Young (1773–1829) in 1807, now known as Young’s modulus.
1732	Anders Celsius (1701–1744)	Thermometer scale calibration based on pure water phases.
1733	Daniel Bernoulli (1700–1782)	Acoustics, mechanical vibrations, and fluid dynamic principles introduced. Definition of the fundamental frequency and higher harmonics with supporting elaborate mathematical analysis (solutions to differential equations).
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases.
1743	Jean-Baptiste le Rond d’Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> .
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current.”
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1762	Joseph Black (1728–1799)	Realization of the concept of latent heat.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days.
1783	Antoine Laurent de Lavoisier (1743–1794)	Discovery of oxygen and the chemical impact.
1783	Joseph-Michel Montgolfier (1740–1810) and Jacques-Étienne Montgolfier (1745–1799)	Hot-air balloon; buoyancy.
1785	Jacques Alexandre César Charles (1746–1823)	Charles’s law, expansion of gases.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery.
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.
1807	Thomas Young (1773–1829)	Formal introduction of the Young's modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783).
1821	Michael Faraday (1791–1867)	Discovery of electromagnetic rotation, leading to his law on electromagnetic induction in 1831. Meanwhile, in 1923 Michael Faraday experimentally verified the concept of refrigeration, introduced based on the work of John Dalton (1766–1844) in 1802 and William Cullen (1710–1790) in 1756.
1823	Nicéphore Niépce (1765–1833) and Louis Jacques-Mandé Daguerre (1787–1851)	Introduction of photography, using the earlier efforts of Albertus Magnus (1193–1280) with his discovery of silver nitrate, and Georg Fabricius (1516–1571) who discovered silver chloride.
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Refrigerator for general public.
1827	Benoît Fourneyron (1802–1867)	First water turbine.
1831	Michael Faraday (1791–1867) and Joseph Henry (1797–1878)	Law of induction, leading to the development of the electric generator.
1840	Jean Léonard Marie Poiseuille (1799–1869) and Gotthilf Heinrich Ludwig Hagen (1797–1884)	Pressure drop for incompressible fluids with respect to laminar flow.
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin.
1851	Jean Bernard Léon Foucault (1819–1868)	Foucault pendulum, illustrating the impact of the earth's rotation on motion.
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule–Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid, or liquid. Sometimes also found as the Joule–Kelvin effect.
1854	Robert Wilhelm Eberhard Bunsen (1811–1899)	Bunsen burner.
1859	James Clerk Maxwell (1831–1879)	Description of the distribution law of molecular velocities, also relating to the concept of Brownian motion.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1861	Augustin Mouchot (1825–1911)	Presentation of the use of solar energy as a source for personal energy consumption.
1866	Ludwig Eduard Boltzmann (1844–1906) and Josiah Willard Gibbs (1839–1903)	Statistical mechanics, correlating energy, and heat, to the movement (velocity).
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential, a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1873	James Clerk Maxwell (1831–1879)	Theory of electromagnetic radiation: <i>Treatise on Electricity and Magnetism</i> . James Maxwell made use of the prior work by Wilhelm Eduard Weber (1804–1891) and Johann Carl Friedrich Gauss {Gauß} (1777–1855).
1880	Johannes Diederik van der Waals (1837–1923)	Description of the covalent bond. Van der Waals equation.
1887	Heinrich Rudolf Hertz (1857–1894)	Radar development. Detection of electromagnetic radiation (radio waves). Heinrich Hertz also discovered that certain metal plates will generate electricity when exposed to light: photoelectric effect.
1894	Max Karl Ernst Ludwig Planck (1858–1947)	Black body radiation.
1895	Wilhelm Röntgen (1845–1923)	Discovery of X-ray (Röntgen rays).
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.
1897	Guglielmo Marconi, 1st Marquis of Marconi (1874–1937)	Introduction of wireless communications and radio.
1896	Manya (Marie) Skłodowska Curie (1867–1934)	General discovery of the concept of radiation and the various levels of energy, particulate and electromagnetic radiation involved in certain decay processes. Discoveries were made with the help of an electrometer that was developed approximately 15 years earlier by her husband Pierre Curie (1859–1906) and his brother Jacques Curie (1856–1941). The first radioactive element they discovered was uranium.
1898	Antoine Henri Becquerel (1852–1908)	Introduction of units for radioactivity radiation. Collaborator with Manya (Marie) Skłodowska Curie (1867–1934). Henri Becquerel, Marie Curie, and Pierre Curie shared the Nobel Prize in Physics for their radioactivity discoveries in 1903.
1900	Ferdinand Adolf Heinrich August Graf von Zeppelin (1838–1917)	Successful dirigible, gas-filled air floatation device with propulsion.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1900	Max Karl Ernst Ludwig Planck (1858–1947)	Inception of quantum mechanics.
1905	Albert Einstein (1879–1955)	Theory of special relativity: relationship between space and time. (1) The laws of physics are invariant in any and all inertial systems, based on a nonaccelerating frame of reference configuration and (2) the speed of light in vacuum is the identical to all observers, regardless of the motion of the frame of reference for the light source. The theory is “special” since it applies to the special case of inertial reference frames.
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1916	Albert Einstein (1879–1955)	Theory of general relativity: geometric theory of gravitation. The “general” aspect defines the unified description of gravity as a geometric property of both space and time, also referred to as “space-time.” In particular, the curvature of space-time is uniquely related to the momentum and energy of any kind of matter and radiation that are present.
1923	Lester Halbert Germer (1896–1971) and Clinton Joseph Davisson (1881–1958)	Experimental confirmation of the wave–particle duality for electromagnetic radiation.
1926	Erwin Schrödinger (1887–1961)	Quantum mechanical wave equivalence, wave theory for atomic and nuclear energy configurations.
1926	Mark Cowley Lidwell (1878–1969) and Edgar Harold Booth (1893–1963)	Rudimentary, but effective, external cardiac pacemaker design.
1927	Werner Karl Heisenberg (1901–1976)	Uncertainty principle; impossibility to know both the location and the momentum (energy) of a system with absolute accuracy simultaneously. This also removed the causality aspect from events, and substitutes probabilistic distributions.
1930	Richard Buckminster Fuller (1895–1983)	Mechanical engineering and engineering architecture, as well as chemistry; bucky-ball, multipoint connections in both chemical structures and mechanical structures.
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962); Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more. One notable result is the creation of nuclear power plants.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1937–1959	Chester Floyd Carlston (1906–1968)	Photocopy machine, patented in 1942. The first photocopier was offered for sale by the Haloid company in 1959, later renamed Xerox.
1948	Julian Schwinger (1916–1994), Richard Phillips Feynman (1918–1988), and Sin-Itiro Tomonaga (1906–1979)	Quantum electrodynamics and quantum field theory.
1950	John Alexander Hopps, (1919–1998)	Introduction of the “portable” (45 kg) cardiac pacemaker, based on the earlier work by Mark Lidwell (1878–1969) and Edgar Harold Booth (1893–1963) in 1926. This led, with the development of microprocessors, to the first implantable pacemaker in 1958 by William Chardack (1919–2011) and Wilson Greatbatch (1919–2011).
1956	Paul Winchell {Wilchinsky} (1922–2005)	Artificial heart (Jarvik 7).
1969		First lunar landing; Apollo 11: Neil Armstrong (1930–2012), Michael Collins (1930–) (commander of lunar orbitor module), and Buzz Aldrin {Edwin Eugene Aldrin Jr} (1930–).
1968	Stephen Hawking (1942–), George Francis Rayner Ellis (1939–), and Roger Penrose (1931–)	“Big Bang theory” for the origin of the universe as we know it and how we observe the physical parameters evolve. The concept was introduced by Edwin Hubble (1889–1953) in rudimentary form in 1929.
2008	CERN, Switzerland	Large Hadron Collider, beginning of operations. To date no evidence supporting string theory or supersymmetry has been collected.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland.

Geo

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 600 BC	China; India	Documented use of magnetic compasses; the lodestone. More specific documented use dates to the Han Dynasty (ca. 206 BC).
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Introduction of metrology, accurate measurements of objects, phenomena, events, and conditions (e.g., atmospheric conditions).
430 BC	Socrates (469 BC–399 BC)	Scholar and educator, introducing analytical thinking.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
350 BC	Aristotle (384 BC–322 BC)	Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle used geological and atmospheric record keeping for the prediction of weather conditions (meteorology). First documented use of a scientific approach to weather forecasting.
ca. 250 BC	Archimedes (287 BC–212 BC)	Revealed the properties that define buoyancy. The base principles relate to the tectonic plate mechanics.
ca. 240 BC	Eratosthenes (ca. 276 BC–ca. 195 BC)	Derivation of the circumference of the earth using trigonometry (round earth was already a concept).
50	Gaius Plinius Secundus (23–79), known as: Pliny the Elder	Publication of the magnetic action of the lodestone in his publication: <i>Naturalis Historia</i> . A rather detailed description of the use of magnetism for geographical location determination is described.
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεὺς] (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. The base of this methodology formed the principle understanding of the movement of atmospheric air masses in future years.
120	Claudius Ptolemy {Ptolemaeus} [Πτολεμαῖος] (90–168)	Geographic recordings of a significant part of the Islamic and western world (i.e., Roman and Persian Empire), living in Egypt, as a Roman with Greek education. His cartography extended all the way out, including parts of China (discovered in fifteenth century). He specifically developed arithmetical techniques for calculating astronomical phenomena, under the teachings of Babylonian astronomers. Also known as: بطليموس (Batlaymus; Arabic). Combining the cartography with the ancient Chinese knowledge of the earth's magnetic field formed early recording of the location of the North and South pole, however rudimentary, only a portion of the earth had been mapped. later documentation with a detailed world map provided an indication of the migration of the magnetic poles.
ca. 132	Zhang Heng (78–139) of China's Han dynasty	Documented construction and operation of the first seismic instrument.
ca. 1000	Abu al-Rayhan al-Biruni (973–1048)	Documented hypothesis of the movement of the tectonic plates, specifically the assumed location of India, which in early history would have been ocean. Realistically: continental drift split the continents from one “continuous” land mass about 200 million years ago, end of Paleozoic era; which is often considered to hold the beginning of animal life.
1,050		Full-scale use of the compass for geographical orientation in the western and far-eastern world.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1,269	Petrus Peregrinus of Maricourt	Formal description of the use of the compass during seafaring expeditions.
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man,” involved in all aspects of cultural evolution, science, engineering, politics, and art.
1535	Joao de Castro (1500–1548)	Recognition of the deviation between the magnetic north and the geographic north.
1543	Nicolaus Copernicus (1473–1543); alias of Niclas Koppernigk	Introduction of the heliocentric model for the earth, sun, and other planets. This follows the statement by the astronomer from Greece: Aristarchus of Samos (ca. 310–ca. 230 BC), made more than 1700 years prior. The scientific observations made by Copernicus were validated by Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.
ca. 1600	William Gilbert (1544–1603)	Experimentalist. Description of magnetism, in his work <i>De magnete, magnetisque corporibus, et de magno magnete tellure</i> . The compass had been in use since 206 BC (Chinese Han Dynasty: 206 BC–220 AD; maybe even earlier, during the Qin Dynasty: 221 BC–207 BC), in the European and Persian area since the thirteenth century.
ca. 1540		Realization that the magnetic field line running “north to south” (isogones) are not straight lines, but have complex tracks, even loops as a function of the geographical locations. Confirmed by Willem van Bemmelen (1868–1941) based on the magnetic direction recording made by the ships as a function of geographical location traveling for the East India Company (mercantile trips to the Dutch colonies), between the Netherlands and Indonesia (around Cape Horn, South Africa).
ca. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re) introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei was remanded under house arrest by the Roman Inquisition for his views and teachings where he died after 9 years. This was the trailing end of the Renaissance period.
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits. Vortices are found in geological phenomena such as cyclones (hurricanes), maelstrom, and aspects of magma flow.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1650	Pierre de Fermat (1601–1665)	Developed infinitesimal (elementary) calculus. Instrumental in the development of the mathematical description of the wave refraction principle. Several of Fermat's mathematical efforts in solving polynomial equations extended beyond the two-dimensional plane where most mathematicians were comfortable, which has direct implications in seismic wave propagation, although not investigated in his day to great extent.
ca. 1655	Christiaan Huygens (1629–1695)	Invention of a clockwork mechanism capable of timekeeping while at sea in order to allow for accurate geographical measurements.
1650	Blaise Pascal (1623–1662)	Pascal's law, pressure in a container applies an equal force on all surface of the enclosure. The unit for pressure under atmospheric conditions uses the unit Pascal in his honor.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas relating to partial pressure of atmospheric constituents and barometric values.
1679	Denis Papin (1647–ca. 1712)	Pressure and thermodynamic and mechanical impacts. Denis Papin worked as an assistant to both Christiaan Huygens (1629–1695) and Robert Boyle (1627–1691). His invention of the pressure cooker bears some resemblance to the conditions found in geysers.
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring. The extended implications are in the mechanics of seismic waves.
ca. 1687	Sir Isaac Newton (1643–1727)	The recognition of gravitational force provided one of the essential building blocks in the geological understanding next to.
1705	Edmond Halley (1656–1742)	Discovery of, and mathematical description of the trajectory for "Halley's comet."
1724	George Graham (1675–1751)	Recognition of the concept of diurnal declination, compass needle during the day.
1750–1800		With the advent of more sophisticated measurement instrumentation (thermometer, barometer, wind velocity meter) meteorology became more scientifically rooted, especially with the interest of a broad range of mathematicians in the dynamics of physics; thermodynamics, motion, wave propagation, and pressure perturbations. The methodology for cartography and for geographic orientation (compass) also had evolved significantly.
1714	Brook Taylor (1685–1731)	Fundamental frequency of vibration; string. Additional work on pure mathematics: Taylor series.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1727	Leonard Euler (1707–1783)	Introduction of the concept of the elastic modulus, experimentally verified by Giordano Riccati (1709–1790) in 1782 and mathematically introduced by Thomas Young (1773 – 1829) in 1807, now known as Young's Modulus.
1732	Anders Celsius (1701–1744)	Thermometer scale calibration based on pure water phases.
1733	Daniel Bernoulli (1700–1782)	Acoustics, mechanical vibrations, and fluid dynamic principles introduced. Definition of the fundamental frequency and higher harmonics, with supporting elaborate mathematical analysis (solutions to differential equations). This laid the foundation for seismic imaging using P-wave (primary wave; longitudinal) and S-wave (secondary wave, or shear wave [transverse]).
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases.
1743	Jean-Baptiste le Rond d'Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> .
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current.”
ca. 1755	Piter van Musschenbroek (1692–1761)	Study of the deviations in the earth's magnetic field lines as a function of altitude, no conclusive data at the time.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1762	Joseph Black (1728–1799)	Realization of the concept of latent heat.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days.
1783	Antoine Laurent de Lavoisier (1743–1794)	Discovery of oxygen and the chemical impact.
1783	Joseph-Michel Montgolfier (1740–1810) and Jacques-Étienne Montgolfier (1745–1799)	Hot-air balloon; buoyancy.
1785	Jacques Alexandre César Charles (1746–1823)	Charles's law, expansion of gases.
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.
1807	Thomas Young (1773–1829)	Formal introduction of the Young's modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783). The Young's modulus plays a significant role in the seismic activity and mechanical deformation as well as the seismic wave propagation in three-dimensional geometry.
1810	Siméon Denis Poisson (1781–1840)	Poisson's analysis of the wave theory of light contributed to the evolution and understanding of interference principles and applications.
1811	Siméon Denis Poisson (1781–1840)	Introduction of the means to quantify the ratio of transverse to axial strain, by means of the Poisson ratio.
1820	William George Horner (1786–1837)	Introduction of the methodology for solving and calculating polynomials (roots): Horner's method. The methods were actually already described 600 years prior by the Chinese mathematician Qin Jiushao (秦九韶), (ca. 1202–1261).
ca. 1825	Baron Augustin-Louis Cauchy (1789–1857)	Pioneer in mathematical and structural analysis of data. Formally introduced several of the modern concepts of calculus. Cauchy also introduced the concept of convergent series, in order to obtain a finite solution.
1840	Jean Léonard Marie Poiseuille (1799–1869) and Gotthilf Heinrich Ludwig Hagen (1797–1884)	Pressure drop for incompressible fluids with respect to laminar flow. Reference to meteorology, wind formation based on arctic versus topical pressure systems.
1842	James David Forbes (1809–1868)	Measurement of seismic wave with the first seismometer, using a weight hanging from springs. Modern seismometers generally measure vibration amplitude in the frequency range from 0.00118 Hz to 500 Hz. The scale (Richter scale) of the seismic activity was introduced by Charles Francis Richter (1900–1985) and Beno Gutenberg (1889–1960) in 1935.
1843–1848	James Prescott Joule (1818–1889)	Empirical verification of the first law of thermodynamics: stating the equivalence of heat and work. This applies to both the source energy for the persisting liquid core (magma) and the work performed by volcanic eruptions and earthquakes.
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin. Reference base for geological events and meteorology.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1850	Rudolf Julius Emanuel Clausius (1822–1888)	Recognition of two basic principles of thermodynamics, later introduced by means of the first and second law of thermodynamics, respectively: energy is constant and entropy tends toward a maximum. Clausius introduced the parameter U , representing the internal energy. Publication of book <i>On the Motive Power of Heat, and on the Laws Which Can Be Deduced from It for the Theory of Heat</i> . Clausius introduced what is now regarded the second law of thermodynamics in 1865 (referred to by William John Macquorn Rankine [1820–1872] as the “thermodynamic function”), as part of any natural thermodynamic process, the sum of the entropies of the participating systems will increase.
1851	Jean Bernard Léon Foucault (1819–1868)	Foucault pendulum, illustrating the impact of the earth’s rotation on motion.
1851	Sir George Gabriel Stokes, 1st Baronet (1819–1903)	Creeping flow, partially applicable to seismology, specifically in the treatment of the mathematical solution for tsunami seismic waves. Specific seismic work of Gabriel Stokes was on a “microscopic” scale in earth-sized dimensions, describing vibrational forces and energy related to driven oscillations while crossing bridges, and the resulting bridge collapses in his days. One of the fall-outs from the bridge vibration and collapse is development of studies in metal fatigue. Furthermore, the work of Stokes contributed to the development of the scientific and engineering support for the construction of high-rise buildings in earthquake-prone geographical regions.
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule–Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid or liquid. Sometimes also found as the Joule–Kelvin effect. The Joule–Thomson effect is an isenthalpic process, which entails that the enthalpy of the fluid is constant during the process, which applies to Joule–Thomson inversion temperature, described in the Linde cycle (Carl von Linde [1842–1934]), offering conditions leading to cloud formation.
1859	James Clerk Maxwell (1831–1879)	Description of the distribution law of molecular velocities.
1861	Augustin Mouchot (1825–1911)	Presentation of the use of solar energy as a source for personal energy consumption.
1865	Gabriel Lamé (1795–1870)	Introduction of the shear modulus and another parameter that is linked through the Poisson ratio (Lamé constants), providing the basis for the introduction of the P-wave and S-wave principles, based on the work of Robert Hooke (1635–1703).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1868	Sultan – Abdülaziz (1830–1876) and Grand Vizier: Mehmed Emin Aali Pasha (1815–1871)	Installation of the “first” geophysical and meteorological observatory: “Rasathane-i Amire” in Constantinople (Istanbul, Turkey): Ottoman Empire.
1873	James Clerk Maxwell (1831–1879)	Theory of electromagnetic radiation: <i>Treatise on Electricity and Magnetism</i> . James Maxwell made use of the prior work by Wilhelm Eduard Weber (1804–1891) and Johann Carl Friedrich Gauss {Gauß} (1777–1855)
1885	John William Strutt, the 3rd Baron Rayleigh (1842–1919)	Introduction of the concept of surface seismic waves. Specifically the surface interface waves, referred to as Rayleigh waves (single surface only), the medium can be of semi-infinite thickness. Also found described under finite thickness plate conditions by Lamb waves (Sir Horace Lamb [1849–1934]).
1887	Heinrich Rudolf Hertz (1857–1894)	Radar development. Detection of electromagnetic radiation (radio waves). Heinrich Hertz also discovered that certain metal plates will generate electricity when exposed to light: photoelectric effect.
1896	Emil Johann Wiechert (1861–1928)	Introduction and verification of the layered model for earth. Emil Johann Wiechert was a pupil of Woldemar Voigt (1850–1919). Emil Wiechert also developed a detailed mathematical model for the seismic activity on earth, with assistance from Beno Gutenberg (1889–1960).
1897	Joseph John Thomson (1856–1940)	Discovery of the electron. The beta particle is one of three decay process that allows for molecular identification and quantification of radioactive activity over time to build a history profile of the geological development processes.
1900	Ludwig Eduard Boltzmann (1844–1906)	Thermodynamic concepts with respect to heat exchange in the earth’s volume, specifically defining the entropy. Boltzmann equation for statistical mechanics, introduced by Ludwig Boltzmann between 1872 and 1875, reformulated by Max Karl Ernst Ludwig Planck (1858–1947). For certain systems also addressed as the Gibbs entropy formula, after Josiah Willard Gibbs (1839–1903).
1902	Maurits Snellen	Discovery of the influence of solar activity on the magnetic field lines used for compass orientation (isogones), sunspots.
1905	Albert Einstein (1879–1955)	Alternate theory of gravity, and his theories of relativity shaped the developing field of relativistic astrophysics.
1911	Augustus Edward Hough Love (1863–1940)	Introduction of the “Love wave”; horizontally polarized (elastic) shear waves (SH waves) in a subsurface layer of semi-infinite dimensions, covered by a finite thickness cover layer. These wave will travel faster than Rayleigh waves, which occur in the surface layer.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1912	Alfred Wegener (1880–1930)	Revelation of the tectonic plate concept and description of continental drift.
1910–1935	Alfred Wegener (1880–1930), Maurice Ewing (1906–1974), Bryan L. Isacks (1942?–), Walter C. Pitman, III (1931–), Frederick Vine (1939–), Drummond H. Matthews (1931–1997), S. Keith Runcorn (1922–1995), Xavier Le Pichon (1937–), Harry Hammond Hess (1905–1969), Robert S. Dietz (1914–1995), V. Hugo Benioff (1899–1968), Dan McKenzie (1942–), Edward Bullard (1907–1980), John Tuzo Wilson (1908–1993), and W. Jason Morgan (1935–)	Development and refinement of the tectonic plate model.
1914	Beno Gutenberg (1889–1960)	Confirmation of the layered model for the structure of the earth globe, introduced by his mentor Emil Johann Wiechert (1861–1928).
1917	Sir Horace Lamb (1849–1934)	Introduction of the concept of evanescent waves, referred to as Lamb waves. Elastic waves traveling in the bulk of a finite thickness plate (i.e., tectonic plate).
1919		The observations made during a total solar eclipse in this year by an expedition from the Royal Astronomical Society and the Royal Society of London confirmed the deviation of starlight in the gravitational field of the sun as predicted by the general theory of relativity. The strongest support for this theory came later from the agreement between the calculated and observed values of the precession of the perihelion of Mercury.
1922	Jacob Aall Bonnevie Bjerknes (1897–1975), Vilhelm Friman Koren Bjerknes (1862–1951), Halvor Skappel Solberg (1895–1974), and Tor Bergeron (1891–1977)	Formulation of pressure fronts and the general movement of air masses.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1924	Robert Stoneley (1894–1976)	Stoneley wave, Rayleigh wave-type interface wave, at a solid-solid interface, traveling with relatively high amplitude. In case the interface is solid-liquid the wave phenomenon is referred to as the Scholte wave (Johan Gerard Jozef Scholte [1907–1970]). Stoneley waves can be reflected and refracted at sharp impedance contrasts at interfaces such as lithology, fractures, and changes in borehole diameter. Moreover, as formation permeability increases, the propagation velocity for Stoneley wave decreases, resulting in dispersion.
1924	Edward Victor Appleton (1892–1965), Arthur Edwin Kennelly (1861–1939) next to Oliver Heaviside (1850–1925)	Initiation of a series of experiments that established the existence and properties of ionized layers in the upper atmosphere. The existence of this type of layers had been postulated by Arthur Edwin Kennelly (1861–1939) in 1902 and, independently, by Oliver Heaviside (1850–1925) to explain the observed implications for long-distance wireless telegraphy. Edward Appleton received the Nobel Prize for Physics in 1947.
1930	Jacob Clay (1882–1955)	Discovery that cosmic ray intensity decreased in going toward the geomagnetic equator. This latitude effect was investigated exhaustively by Arthur Holly Compton (1892–1962), Robert Andrews Millikan (1868–1953), and others.
1932	Victor Hugo Benioff (1899–1968)	Instrument development leading to the monitoring of the movement of the tectonic plates: Benioff seismograph. Additional instrumentation developed by Hugo Benioff is also capable of measuring strain in the earth's upper layer.
1935	Charles Francis Richter (1900–1985) and Beno Gutenberg (1889–1960)	Introduction of the Richter scale for the determination of the magnitude of seismic activity (earthquake). The scale has a base-10 logarithmic foundation. Prior to the Richter scale earthquakes were defined based on their destructive legacy, primarily pertaining to size of structures affected.
1936	Inge Lehmann (1888–1993)	Description of the numerical assessment of data obtained during earthquakes (seismological data) and the image formation of the structure of the earth's structure, divided in shells with different material phase and composition. The image formation is based on what is referred to as S-waves and P-waves. Inge Lehmann discovered and described the shape, size, and composition (rudimentary) of the earth's inner core.
1938	Guy Stewart Callendar (1898–1964)	Description of the concept of global warming resulting from the insulating layer of carbon dioxide exhaust in the atmosphere.
1942; 1947	Johan Gerard Jozef Scholte (1907–1970)	Scholte wave, seismic-type wave that has the characteristics of a Rayleigh wave, but is at the interface between a solid and a liquid, or a solid and an elastic (plastic) solid (e.g., sand).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1950		Dedicated studies initiated to observe the developing global warming concepts.
1953	William Maurice Ewing (1906–1974) and Bruce Charles Heezen (1924–1977)	Discovery of the Great Global Rift: oceanic ridge.
1960		Launch of the first weather satellite.
1995	Roger Lee Easton (1921–2014)	Development of the global positioning concept (GPS).

High Energy

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
13.8 billion years BC	Georges Henri Joseph Édouard Lemaître (1894–1966) and Edwin Powell Hubble (1889–1953)	“The Big Bang”; in 1927 the expanding universe was recognized.
1870	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Unofficial introduction to the mechanism of action for nuclear fusion.
1896	Wilhelm Conrad Röntgen (1845–1923)	Discovery of X-ray radiation.
1896	Henri Becquerel (1852–1908)	Emission of “Becquerel rays” from uranium salts, later identified as alpha particles. Becquerel already recognized that this emission was different from X-ray since it was deflected by means of an applied external magnetic field. Conceptual introduction to the field of radioactivity.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes’s vacuum tube.
1897	Marie Skłodowska-Curie (1867–1934)	Discovery of radioactive isotopes. Marie Curie introduced the term “radioactivity.”
1899	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Emission of alpha particle.
1900	Max Karl Ernst Ludwig Planck (1858–1947) and James Clerk Maxwell (1831–1879)	Formal description of the photon and the energy associated with the electromagnetic wave.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1903	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Discovery of the nuclear decay half-life.
1903	Marie Skłodowska-Curie (1867–1934) and Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Quantification of nuclear decay.
1906	Dmitri Ivanovich Mendeleev (1834–1907)	Periodic Table of Elements.
1908	Johannes Geiger (1822–1945) and Ernest Rutherford (1871–1937)	Development of the Geiger counter, used to measure radioactive radiation.
1909	Francis Aston (1877–1945)	Mass spectrometer mass separation of closely separated isotopes. Highly sensitive mass spectrometer design.
1911	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Rutherford scattering on nuclear level, indication of the existence of the proton. The proton itself was not mentioned until 1932, this time again by Ernest Rutherford.
1912	Victor Francis Hess (1883–1964)	Recognition of high-energy cosmic radiation, observed during a high altitude balloon ride.
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1913	Frederick Soddy (1877–1956)	Formal introduction of the isotope concept.
1914	Niels Henrik David Bohr (1885–1962)	Description of the atomic energy layer model; hydrogen (Bohr atomic model).
1915	Ernest Marsden	Artificial transmutation, associated with radon enclosed by vacuum.
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. Nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.
1919	Ernest Rutherford (1871–1937)	Artificial transmutation, hydrogen formation resulting from collisions of alpha particles with nitrogen, also generating oxygen and gamma rays.
1921	James Chadwick (1891–1974) and Étienne Samuel Biéler (1895–1929)	Strong nuclear force.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1923	Arthur Holly Compton (1892–1962)	Description of the deflection of photons by a charge unit, generally an electron, potentially the nucleus: Compton effect.
1925	Johannes Geiger (1822–1945) and Walther Wilhelm Georg Bothe (1891–1957)	Conservation of energy for atomic and nuclear processes.
1925	Werner Karl Heisenberg (1901–1976)	Uncertainty principle.
~1925		Recognition of the “Coulomb barrier” in nuclear collision, providing a “tunneling” effect for the release of alpha particles.
1927	Werner Karl Heisenberg (1901–1976)	Quantum uncertainty principle.
1927	Paul Adrien Maurice Dirac (1902–1984)	Description of antimatter.
1928	Johannes Geiger (1822–1945) and Walther Müller (1905–1979)	Introduction of an improved Geiger counter: the Geiger–Müller counter, using ionization of a confined gas.
1929	Leo Szilard (1898–1964) and Ernest Orlando Lawrence (1901–1958)	Particle accelerator, cyclotron. The cyclotron can accelerate protons to reach kinetic energy in excess of 700 MeV, with respective radius of 4.6 meter (1946). The first cyclotron was built in 1932, at the University of California Berkeley, California: Tevatron. Cyclotrons are specifically and not exclusively used to create isotopes for use in nuclear medicine, in particular for imaging (e.g., PET) and for cancer treatment.
1930	Walther Wilhelm Georg Bothe (1891–1957) and his student Herbert Becker ()	Observation of a puzzling penetrating “radiation” from beryllium bombarded with alpha particles (helium nuclei). Conceptual introduction to the fission process.
1931	Wolfgang Ernst Pauli (1900–1958)	Introduction of an electrically neutral particle, the neutron. Energy when involved in beta decay up to 0.5 MeV. The experimental verification of the existence of the neutrino was not until 1956 by Frederick Reines (1918–1998) and Clyde Cowan Jr. (1919–1974).
1931	Carl David Anderson (1905–1991)	Discovery of the positron, antiparticle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1932	Sir James Chadwick (1891–1974)	Discovery of the neutron. Student of Ernest Rutherford (1871–1937).
1934	Leo Szilard (1898–1964)	Recognition of nuclear decay chain reactions.
1934	Hideki Yukawa [湯川 秀樹], (1907–1981)	Introduction of mesons and the concept of antimatter.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1934	Ida Noddack (1896–1978)	Formal introduction of the concept of “fission”; however, not recognized by her peers at the time. The fission phenomenon was only recognized when announced by Enrico Fermi (1901–1954) later that year.
1934	Enrico Fermi (1901–1954)	Interaction of slow neutron with nuclei and the resulting decay into different elements, including aluminum and uranium.
1935	Arthur Dempster (1886–1950)	Discovery of the lighter uranium isotope: Uranium-235.
1936	Otto Hahn (1879–1968) and Lise Meitner (1878–1968)	Neutron collision of uranium-induced decay examination.
1937	Carl David Anderson (1905–1991), Seth Henry Neddermeyer (1907–1988), Jabez Curry Street (1906–1989), and Edward C. Stevenson (1937–)	Confirmation of the existence of the meson and muon. Subatomic particles are governed by quantum physics principles, and will exhibit a wave–particle duality. The quantum state energy vectors are represented in Hilbert space.
1938	Niels Henrik David Bohr (1885–1962) and John Archibald Wheeler (1911–2008)	Formal description of the nuclear fission process.
1939	Jerome M. B. Kellogg (1905–?)	Discovery of a finite quadruple moment for the deuteron, requiring a noncentral (tensor) nuclear force configuration.
1940	Otto Robert Frisch (1904–1979)	Development of the detonation mechanism for the first atomic bomb.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962); Enrico Fermi (1901–1954); Eugene Wigner (1902–1995), and dozens more.
1945	Edwin Mattison Mcmillan (1907–1999) next to Vladimir Iosifovich Veksler (1907–1966)	Independent introduction of the principle of the synchrotron. The synchrotron accelerator produces very high-energy particles, as in the Cosmotron, Brookhaven National Laboratory, USA, or Bevatron, Lawrence Berkeley National Laboratory, USA operating at 10 BeV.
1946		Introduction of the term “Lepton”, defining weak nuclear interaction particles; electrons and muons are hence considered leptons.
1947	George Dixon Rochester (1908–2001) and Clifford Charles Butler (1922–1999)	Discovery of the subatomic particle: the “kaon,” k-meson. Introduction of the “strangeness” concept for quarks, although the quark concept had not been introduced. In the elementary particle phenomenology the kaon is a bound state of an up- or down quark with a strange quark (anti-quark).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1947	Maria Goeppert-Mayer (Göppert) (1906–1972)	Theoretical concept development for the understanding of nuclear forces, based on a shell model, similar to the atomic electron model.
1947	William Webster Hansen (1909–1949)	Linear accelerator installation at Stanford University, California.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model for atomic nuclei.
ca. 1952	Ludwig von Helmholtz (1821–1894), Lyman Strong Spitzer, Jr. (1914–1997) and Ronald Richter (1909–1991) and Edward Teller (1908–2003)	Nuclear fusion investigation and start of experimentation. The process was in principle described by Hermann Ludwig Ferdinand von Helmholtz (1821–1894), but is continuously in action at the sun's surface.
1954	Chen-Ning Franklin Yang (1922–2004) and Robert Laurence Mills (1927–1999)	Introduction of “Gauge Theories.” These gauge theories will eventually form the basis for the “standard model.”
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.
1956	Frederick Reines (1918–1998) and Clyde Lorrain Cowan, Jr. (1919–1974)	Experimental confirmation of the neutrino introduced in 1931 by Wolfgang Pauli (1900–1958).
1957	Julian Schwinger (1918–1994), Sidney Bludman (1927–), Sheldon Lee Glashow (1933–), and Hideki Yukawa (1907–1981)	Bosons provide the weak attraction. Initially conceived by Hideki Yukawa (1907–1981) in 1937. These heavy bosons are referred to as W^- and W^+ .
1958	Stanley Mandelstam (1928–2016)	Introduction of Mandelstam variables associated with the concept of “crossing symmetry,” defining numerical quantities that encode the energy, momentum, and scattering angles of particles in a deflection process described in a Lorentz-invariant fashion.
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович Бенедиктович Мигдал] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1961	Murray Gell-Mann (1929–)	Description of elementary particles, eight-fold way of defining “strangeness” for the quark. Formal introduction of the elementary particle “quark” concept, the building blocks for protons and neutrons. The “quark” name is based on an expression in the book <i>Finnegans Wake</i> by James Joyce.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Никола́й Генна́диевич Ба́сов] (1922–2001), and Aleksandr Mikhailovich Prokhorov [Алекса́ндр Миха́йлович Про́хоров] (1916–2002)	Quantum electronics.
1965	Oscar Wallace Greenberg (1932–), Moo-Young Han (1934–), and Yoichiro Nambu [南部陽一郎] (1921–)	Introduction of the concept of “color” change as designation and property for quarks.
1970	Sheldon Lee Glashow (1932–), John Iliopoulos (1940–), and Luciano Maiani (1941–)	Introduction of the charm quark.
1973	Hugh David Politzer (1949–), David Jonathan Gross (1941–), and Frank Anthony Wilczek (1951–)	Discovery associating the quark color theory of the strong interaction to a special property, referred to as “asymptotic freedom.” This “color” property is required to describe the data acquired over the prior period from 1968 to 1969 with respect to the substrate of the proton.
1974	Burton Richter (1931–) and Samuel Chao Chung Ting [Chinese: 丁肇中] (1936–)	Description of charm for the quark.
1975	Carlo Rubbia (1934–), Burton Richter (1931–), Frederick Reines (1918–1998), Jack Steinberger (1921–), Leon Lederman (1922–), Richard Taylor (1929–), Jerome Friedman (1930–), and Martin Perl (1927–2014)	Standard model of particle interaction. Interactions between leptons and quarks, interacting by means of bosons. Listing the contributing scientist that led to the discovery of the various elementary particles, respectively: W and Z boson; charm quark; neutrino; muon–neutrino; muon–neutrino, and b-quark; quarks (general); quarks (general); tau.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1975	Martin Lewis Perl (1927–2014)	Discovery of the tau lepton.
1977	Leon Max Ledderman (1922–)	Discovery of the “beauty” and “bottom” designation for quarks.
1978		Discovery of the “gluon” with the assistance of the PLUTO, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1983	Collider Detector at Fermilab	World’s first and at the time highest-energy particle accelerator, colliding antiprotons and protons propelled to center-of-mass energy reaching 2 TeV.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland. The Large Hadron Collider construction started in 1998 and produces particle acceleration with respective energy levels for protons at up to 4 teraelectronvolts (0.64 microjoules), or lead nuclei: 2.76 TeV per nucleon or 574 TeV per nucleus. The proton energy level was increased to 6.5 TeV in 2015.

Imaging

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 410 BC	Mozi (ca. 470 BC–390 BC)	Chinese philosopher. Description of the use of a pin hole for the projection of an image on a wall of a darkened compartment (room); the initial concept of the camera obscura.
350 BC	Aristotle (384 BC–322 BC)	Documented recordings of a solar eclipse based on the principles of the camera obscura. His image formation was based on the projection of the sun through gaps between the leaves of a tree.
ca. 300 BC	Euclid of Alexandria (ca. 350 BC–280 BC)	Publication of the treatise on light: <i>Optics</i> (Ὀπτικά), describing the principles of the image formation for light traveling in straight lines, the camera obscura, next to general vision aspects.
1480	Leonardo da Vinci (1452–1519)	Experimentation with image formation using an ox eye from which he had scraped the retina, providing a lens with “screen” that forms an image. Additional experimentation with the principles of the camera obscura for image projection.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1560	1560: Bernardino de Sahagún (ca. 1499–ca. 1590), 1565: Nicolás Monardes (1493–1588), 1819: Edward Daniel Clarke (1769–1822), 1822: René Just Haüy (1743–1822), 1833: David Brewster (1781–1868), and 1933: Aleksander Jabłoński (1898–1980)	Fluorescence imaging and spectroscopy. The principles of fluorescence are captured by the Jablonski diagram.
1590–1608	Hans Jansen (father of Zacharias) and Zacharias Jansen (1580–1640) and later Hans Lippershey (1570–1619).	Introduction of the optical microscope.
1610	Galileo Galilei (1564–1642)	Improvements to the microscope design by introducing focusing capabilities.
1640	Antonie van Leeuwenhoek (1632–1723)	Refined microscope design. Beginning of microbiology and large-scale microscopic investigations.
1794	Lazzaro Spallanzani (1729–1799)	First documented outline of waves in spatial orientation, forming the foundation for modern ultrasonic imaging.
1816	René Théophile-Hyacinthe Laennec (1781–1826)	Introduction of the stethoscope.
1826	Jean-Daniel Colladon (1802–1893)	Use of ringing a church bell for underwater range finding. Rudimentary “ultrasound” principle.
1864	August Joseph Ignaz Toepler (1836–1912)	Schlieren imaging, refraction of light in a substance as a function of local density or local chemical concentration. Also referred to as “shadow imaging.”
1880	Francis Galton (1822–1911)	Construction of a device capable of generating sound waves of 40,000 Hz. Furthering the imaging capabilities with respect to ultrasound, initially attempted to mimic the observation techniques used by bats.
1880	Paul-Jacques Curie (1855–1941) and Pierre Curie (1859–1906)	Discovery of electric charges emerging on the surfaces of certain crystals, which are subjected to pressure or tension (shear or normal stress). This is referred to as the piezoelectric effect. Supporting technology for ultrasound imaging.
1895	Wilhelm Conrad Röntgen (1845–1923)	Primary X-ray imaging feasibility.
1900	Max Karl Ernst Ludwig Planck (1858–1947)	(Planck’s) radiation law, describing the concept of black body radiation used in thermographic imaging.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1915	Paul Langevin (1872–1946)	Introduction of “hydrophone” for underwater detection of obstacles.
1922	Erwin Rudolf Josef Alexander Schrödinger (1887–1961) and Hermann Klaus Hugo Weyl (1885–1955)	Introduction of the quantum mechanical principles, which formed the basis for several imaging techniques.
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all object in motion. Matter wave, propagating with the de Broglie wavelength.
1926	Hans Busch (1884–1973); Leó Szilárd (1898–1964)	Electron microscopy, transmission (TEM), respectively, reflection/scanning (SEM). The resolution principle is based on the wave motion of the moving electron, propagating with the de Broglie wavelength, as a function of the applied energy.
1927	Wolfgang Ernst Pauli (1900–1958), Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles. This formed the foundation for the development of the NMR imaging system: nuclear magnetic resonance (MRI).
1928	Sir Chandrasekhara Venkata Raman (1888–1970)	Raman spectroscopy.
1937	Karl Dussik (1908–1968)	First recorded event of medical use of ultrasonic imaging.
1946	Felix Bloch (1905–1983) and Edward Mills Purcell (1912–1997)	Fundamental concept introduction providing the mechanism of action for magnetic resonance imaging (MRI).
1951	Erwin Wilhelm Müller (1911–1977)	(Scanning) Helium ion microscopy. The basic principles are very similar to the SEM. The He ion microscope uses both the atomic and molecular interaction of the incident helium ions for “density imaging” on the observed target as well as Rutherford backscattering spectroscopy to derive material properties. In comparison to the SEM, He ion microscope produces 3 to 9 secondary electrons, versus only one for SEM. The work of Erwin Müller on the field ion microscope provided the operational foundation. Erwin Müller first introduced the field emission electron microscope in 1951. The first operational He ion microscope was produced in the first decade of the twenty-first century.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1951+	Douglas Howry (1920–1969) and Joseph H. Holmes (1902–1982)	Pioneering two-dimensional B-mode ultrasound imaging.
1957	Marvin Lee Minsky (1927–)	Confocal microscopy.
1957	Herman P. Schwan (1915–2005)	Bioelectric impedance tomography (electric impedance tomography) and dielectric spectroscopy. Imaging mechanism based on the Maxwell–Wagner effect (polarization); based on the work of James Clerk Maxwell (1831–1879) and Karl Willy Wagner (1883–1953) in the early part of the twentieth century. The Maxwell–Wagner polarization mechanism, which reveals very large effective electric permittivity on scales larger than molecular size. The polarization can be artificially induced and has an associated specific (characteristic) relaxation time. Note: Herman Schwan (Schwann) is sometimes referred to as the “founding father of biomedical engineering.” One of the examples of bioelectric impedance tomography outside the use on humans is in the food industry. Impedance tomography is also used in geological investigation; geophysics application.
1957+	David Edmund Kuhl (1929–), Luke Chapman (), and Roy Edwards ()	Positron emission tomography (PET).
1971	Sir Godfrey Newbold Hounsfield (1919–2004) and respectively Allan MacLeod Cormack (1924–1998)	Computed tomography.
1973	Paul Christian Lauterbur (1929–2007)	First operational MRI machine.
1981	Gerd Binnig (1947–) and Heinrich Rohrer (1933–2013)	Design of the scanning tunneling microscope (STM).
1986	Gerd Binnig (1947–), Heinrich Rohrer (1933–), Calvin Quate (1923–), and Christoph Gerber (1942–)	Initial concepts for the atomic force microscope (AFM) were introduced.
1989	Paul K. Hansma (1946–), B. Drake (), O. Marti (), S.A. Gould (), and C.B. Prater ()	Scanning ion-conducting microscope. Imaging technique with close correlation to superconductivity.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1990	Naohiro Tanno () and various groups with refinements by the MIT group consisting of David Huang (), James G. Fujimoto (), Carmen A. Puliafito (), and others.	Optical coherence tomography.

Instrumentation

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
6000 BC–2000 BC	Stone Age	Mechanical labor and tool fabrication.		Coherence tomography
				MRI
ca. 6000 BC		First recorded use of floatation devices: boats. This illustrated the Archimedes principle (Archimedes [287 BC–212 BC]), but no documented descriptions on the floatation principles from those days.		PET
				Ultrasound
ca. 4000 BC	Eastern Europe	First recorded drawing of craft with rudimentary wheels.		X-ray
				mass spectrometer
4000 BC	Mesopotamia and Egypt	Documented recording of the construction of shelter, abandoning the nomadic structure.		Geiger counter
				Geiger–Muller
ca. 3500 BC		First documented installation of sewer systems, primarily run-off.		
ca. 3300 BC	Egypt	Drawings of sailboats.		
ca. 3000 BC		Traceable use of a potter's wheel used for the construction of crockery.		
3300 BC–1000 BC	Bronze Age	Smelting and forging of soft metals using low heat: copper, tin, gold. This age also introduces the written documentation.		
2700 BC–2500 BC	Egypt	Construction of pyramids, requiring advanced mechanical engineering efforts and architectural design (civil engineering).		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
ca. 1000 BC	Qanat aqueduct; Perzia	Water supply over a length greater than 71 km, and potential relation with sewer as a secondary use for liquid transport as part of the civil engineering efforts.		
1000 BC–700 AD	Iron Age	Higher heat requirements and more detailed tool manufacturing, introducing scientific and engineering challenges. Historical tracking of processes and developments and philosophies. Introduction of complicated mechanisms and requiring detailed analytical thinking.		
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Introduction of standardized and validated metrology.		
ca. 360 BC	Plato (427 BC–347 BC)	Rudimentary astronomy record keeping.		
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca. 80 BC–10 BC)	Roman engineering architect and civil engineer. Vituvius served under Gaius Julius Caesar (100 BC–44 BC). In the army position he was also charged with the care of the infirmed, where he used early biomedical engineering approaches for novel diagnosis and treatment.		
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεύς] (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. A set of two books <i>The Pneumatica</i> describes mechanical devices worked by air, steam, or water pressure. Also known as Heron of Alexandria. He invented a steam-powered engine called the “Æolipile.”		
120	Claudius Ptolemy {Ptolemaeus} [Πτολεμαῖος] (90–168)	Geographic recordings of a significant part of the Islamic and western world (i.e., Roman and Persian Empire), living in Egypt, as a Roman with Greek education. His cartography extended all the way out, including parts of China (discovered in fifteenth century). He specifically developed arithmetical techniques for calculating astronomical phenomena, under the teachings of Babylonian astronomers. Also known as بطليموس (Batlaymus; Arabic)		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
644		Wind-powered devices developed by the Persians.		
1010	Eilmer of Malmesbury, eleventh century Benedictine monk	First documented successful flight, performed with a wooden frame lined with parchment, traveling approximately 200 m in free-fall from a 18-m elevation.		
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man”, involved in all aspects of cultural evolution, science, engineering, politics and art.		
1503	Gregor Reisch (1467–1525)	Detailed outline of the state-of-the-art science and engineering knowledge to date, including human anatomical drawings in the publication: <i>Margarita Philosophica</i> . The total works of Gregor Reisch form a series of twelve (12) books compiling an encyclopedia describing topics ranging from Latin grammar, to dialectics, rhetoric, arithmetic, music, geometry, astronomy, physics, natural history, physiology, psychology, and ethics.		
1512	Gregorius Reisch (1467–1525)	Introduction of the concept of the theodolite, used for topography and geographic location determination.		
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.		
ca. 1600	William Gilbert (1544–1603)	Experimentalist. Description of magnetism, in his work: <i>De magnete, magnetisque corporibus, et de magno magnete tellure</i> . The compass had been in use since 206 BC (Chinese Han Dynasty: 206 BC–220 AD; maybe even earlier, during the Qin Dynasty: 221 BC–207 BC), in the European and Persian area since the thirteenth century.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
ca. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re)introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei was remanded under house arrest by the Roman Inquisition for his views and teachings where he died after 9 years. This was the trailing end of the Renaissance period.		
1558	Giambattista della Porta (1535–1615)	Incorporation of a lens in the opening of a camera obscura—improved the image formation capabilities.	New	
~1590	Zacharius Janssen (1585–1632)	Constructed a compound microscope with a converging objective lens and a diverging eye lens.		
1604	Johannes Kepler (1571–1630)	In his book <i>Ad Vitellionem Paralipomena</i> , Kepler suggested that the intensity of light from a point source varies inversely with the square of the distance from the source, that light can be propagated over an unlimited distance, and that the speed of propagation is infinite. He explained vision as a consequence of the formation of an image on the retina by the lens in the eye and correctly described the causes of long-sightedness and short-sightedness. Conforming the heliocentric model calculated by Nicolaus Copernicus (1473–1543).		
1604	Johannes Kepler (1571–1630)	Formal introduction of the term “camera obscura.”	new	
1608	Hans Lippershey (1570–1619)	Constructed a telescope with a converging objective lens and a diverging eye lens.		
1609	Galileo Galilei (1564–1642)	Construction of his own version of the telescope design of Hans Lippershey (1570–1619) and used it for astronomical observations. Galileo documented several astronomical discoveries including the four (4) moons of Jupiter.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1611	Giovanni Demisiani (?–1614)	Introduced the term “telescope” for his device with three times (3X) magnification.	new	
1611	Johannes Kepler (1571–1630)	In his book <i>Dioptrice</i> an explanation is provided for the principles involved in the convergent/divergent lens telescopes and microscopes. The telescope could be constructed using a converging objective and a converging ocular lens. The lens assembly description resembles that for the telephoto lens. Kepler also discovered total internal reflection, but could not effectively describe the optical and geometric relationship between the angle of incidence and the angle of refraction.		
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits. Descartes also made an illustration of the earth’s magnetic field configuration in 1644, in his model the moon and celestial objects participated in the formation of the path of the magnetic field lines. Based on the limited experimental observations available in his time the premise was still not bad.		
~1618	Christopher Scheiner (1573–1650)	Constructed a telescope of the type suggested by Johannes Kepler (1571–1630) with converging objective lens system. This type of telescope become the standard “astronomical telescope.”		
1632	Evangelista Torricelli (1608–1647)	Introduction of the barometer; essential in weather prediction; meteorology.		
1650	Blaise Pascal (1623–1662)	Pascal’s law, pressure in a container applies an equal force on all surface of the enclosure		
ca. 1655	Christiaan Huygens (1629–1695)	Invention of a clockwork mechanism capable of timekeeping while at sea in order to allow for accurate geographical measurements.		

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas as a potential “shock absorber,” acting similar to a spring.		
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” powered by gun powder. Huygens introduced several concepts of mechanical engineering and described the mechanism of shock waves. Christiaan Huygens is most known for his lens manufacturing and optical design of telescopes. The mathematical efforts of Christiaan Huygens in probability theory were far advanced and he collaborated with the mathematician Pierre de Fermat (1601–1665) from France.		
1679	Denis Papin (1647–ca. 1712)	Pressure and thermodynamic and mechanical impacts.		
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring.		
ca. 1687	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced several laws of motion. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action-reaction, gravitational acceleration, inertia and force with respect to acceleration. Introduction of the three laws of motion.		
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine; using information obtained by Denis Papin (1647–c. 1712).		
1705	Edmond Halley (1656–1742)	Discovery of, and mathematical description of the trajectory for “Halley’s comet”.		
1712	Thomas Newcomen (1664–1729)	Construction of a “atmospheric” steam engine.		
1714	Brook Taylor (1685–1731)	Fundamental frequency of vibration; string. Additional work on pure mathematics: Taylor series.		

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1727	Leonard Euler (1707–1783)	Introduction of the concept of the elastic modulus, experimentally verified by Giordano Riccati (1709–1790) in 1782 and mathematically introduced by Thomas Young (1773–1829) in 1807, now known as Young's modulus.		
1729/1733	Chester Moore Hall (1703–1771)	Construction of achromatic compound lenses using components consisting of glasses with different refractive indices. Construction of first refracting telescope that has chromatic aberration correction.		
1732	Anders Celsius (1701–1744)	Thermometer scale calibration based on pure water phases.		
1733	Daniel Bernoulli (1700–1782)	Acoustics, mechanical vibrations, and fluid dynamic principles introduced. Definition of the fundamental frequency and higher harmonics, with supporting elaborate mathematical analysis (solutions to differential equations).		
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases		
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.		
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam powered automobile, the predecessor to the internal combustion automobile.		
1783	Joseph-Michel Montgolfier (1740–1810) and Jacques-Étienne Montgolfier (1745–1799)	Hot-air balloon; buoyancy.		
1785	Jacques Alexandre César Charles (1746–1823)	Charles's law, expansion of gases.		
1800	Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827)	Introduction of the battery.		

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.		
1807	Thomas Young (1773–1829)	Formal introduction of the Young's Modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783).		
1821	Michael Faraday (1791–1867)	Discovery of electromagnetic rotation, leading to his law on electromagnetic induction in 1831. Meanwhile, in 1923 Michael Faraday experimentally verified the concept of refrigeration, introduced based on the work of John Dalton (1766–1844) in 1802 and William Cullen (1710–1790) in 1756.		
1823	Nicéphore Niépce (1765–1833) and Louis Jacques-Mandé Daguerre (1787–1851)	Introduction of Photography, using the earlier efforts of Albertus Magnus (1193–1280) with his discovery of silver nitrate, and Georg Fabricius (1516–71) who discovered silver chloride.		
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Refrigerator for general public.		
1826	Jean-Daniel Colladon (1802–1893)	Use of ringing a church-bell for underwater range-finding. Rudimentary “ultrasound” principle.		
1827	Benoît Fourneyron (1802–1867)	First water turbine.		
1831	Michael Faraday (1791–1867) and Joseph Henry (1797–1878)	Law of induction, leading to the development of the electric generator.		
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin.		
1851	Jean Bernard Léon Foucault (1819–1868)	Foucault pendulum, illustrating the impact of the earth's rotation on motion.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule–Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid, or liquid. Sometimes also found as the Joule–Kelvin effect		
1854	Robert Wilhelm Eberhard Bunsen (1811–1899)	Bunsen burner.		
1861	William Froude (1810–1879)	Applications to ship design, reducing the roll of a ship by means of a keel. The hydrodynamic behavior of the hull of a ship could be gauged based on the Froude number, derived from a set of experimental obtained data points.		
1880	Francis Galton (1822–1911)	Construction of a device capable of generating sound waves of 40,000 Hz. Furthering the imaging capabilities with respect to ultrasound, initially attempted to mimic the observation techniques used by bats.		
1887	Heinrich Rudolf Hertz (1857–1894)	Radar development. Detection of electromagnetic radiation (radio waves). Heinrich Hertz also discovered that certain metal plates will generate electricity when exposed to light: photo-electric effect.		
1895	Wilhelm Conrad Röntgen (1845–1923)	Primary X-ray imaging feasibility.		
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.		
1897	Guglielmo Marconi, 1st Marquis of Marconi (1874–1937)	Introduction of wireless communications and radio.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1898	Antoine Henri Becquerel (1852–1908)	Introduction of units for radioactivity radiation. Collaborator with Many (Marie) Skłodowska Curie (1867–1934). Henri Becquerel, Marie Curie, and Pierre Curie shared the Nobel Prize in Physics for their radioactivity discoveries in 1903.		
1900	Ferdinand Adolf Heinrich August Graf von Zeppelin (1838–1917)	Successful dirigible, gas-filled air floatation device with propulsion.		
1904	John Ambrose Fleming (1849–1945)	Application of the Edison effect to make the first thermionic valve (“radio” tube).		
1906	Lee De Forest (1873–1961)	Construction of the first audion (triode) by introducing a grid into a Fleming valve, tube electronics.		
1907–1912	Joseph John Thomson (1856–1940)	Devised methods of positive ray analysis. These processes formed the beginning of mass spectroscopy.		
1909	Guglielmo Marconi (1874–1937) and Carl Ferdinand Braun (1850–1918)	Were jointly awarded the Nobel Prize in Physics—the former for combining the basic knowledge about Hertzian waves to produce wireless telegraphy, and the latter for the study, production, and use of electrical oscillators. Braun also developed the Braun tube, called the “cathode-ray” tube in the United States.		
1911	Charles Thomson Bees Wilson (1869–1959)	Construction of the first expansion cloud chamber, used for particle research. This is one of the most important device in nuclear physics. Charles Wilson was awarded the Nobel Prize in Physics jointly with Arthur Holly Compton (1892–1962) in 1927.		
1915	Paul Langevin (1872–1946)	Introduction of “hydrophone” for underwater detection of obstacles.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. Nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.		
1925	Walter M. Elsasser (1904–1991)	Predicted from de Broglie theory illustrating how electrons could be diffracted by crystals.		
1926	Mark Cowley Lidwell (1878–1969) and Edgar Harold Booth (1893–1963)	Rudimentary, but effective, external cardiac pacemaker design.		
1926	Hans Busch (1884–1973); Leó Szilárd (1898–1964)	Electron microscopy, transmission (TEM), respectively, reflection/scanning (SEM). The resolution principle is based on the wave motion of the moving electron, propagating with the de Broglie wavelength, as a function of the applied energy.		
1930	Richard Buckminster Fuller (1895–1983)	Mechanical engineering and engineering architecture, as well as chemistry; Bucky-ball, multipoint connections in both chemical structures and mechanical structures.		
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.		
1932	Ernest Orlando Lawrence (1901–1958) and Milton Stanley Livingston (1905–1986)	Construction of the first cyclotron. Ernest Lawrence received the Nobel Prize in Physics in 1939.		
1933	Patrick M. S. Blackett (1897–1974) and Guiseppe P. S. Occhialini (1907–1993)	Obtained the first cloud chamber photographs of electron–positron pair production.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1937	Karl Dussik (1908–1968)	First recorded event of medical use of ultrasonic imaging.		
1940	Louis Leprince-Ringuet (1901–2000)	Obtained the first cloud chamber photograph of a collision between a meson and an electron, from which the mass of the meson could be derived.		
1940	Donald William Kerst (1911–1993)	Made the first betatron, an induction type accelerator.		
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more. One notable result is the creation of nuclear power plants.		
1937–1959	Chester Floyd Carlson (1906–1968)	Photocopy machine, patented in 1942. The first photocopier was offered for sale by the Haloid company in 1959, later renamed Xerox.		
1947	Hartmut Paul Kallmann (1896–1978), next to John Wesley Coltman (1915–) next to Fitz-Hugh Ball Marshall (1912–)	Developed scintillation counters.		
1948	Dennis Gabor (1900–1979)	Description of the principles of wavefront reconstruction, evolving into holography.	c	
1950	John Alexander Hopps, (1919–1998)	Introduction of the “portable” (45 kg) cardiac pacemaker, based on the earlier work by Mark Lidwell (1878–1969) and Edgar Harold Booth (1893–1963) in 1926. This led, with the development of microprocessors, to the first implantable pacemaker in 1958 by William Chardack (1919–2011) and Wilson Greatbatch (1919–2011).		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1951	Erwin Wilhelm Müller (1911–1977)	(Scanning) Helium ion microscopy. The basic principles are very similar to the SEM. The He ion microscope uses both the atomic and molecular interaction of the incident helium ions for “density imaging” on the observed target as well as Rutherford backscattering spectroscopy to derive material properties. In comparison to the SEM the He ion microscope produces 3 to 9 secondary electrons, versus only one for SEM. The work of Erwin Müller on the field ion microscope provided the operational foundation. Erwin Müller first introduced the field emission electron microscope in 1951. The first operational He ion microscope was produced in the first decade of the twenty-first century.		
1951+	Douglas Howry (1920–1969) and Joseph H. Holmes (1902–1982)	Pioneering two dimensional B-mode ultrasound imaging.		
1952		Brookhaven National laboratory was the first to achieve the acceleration of particles to the giga-electron-volt energy range: 2.3-Gev protons.		
ca. 1952	Ludwig von Helmholtz (1821–1894), Lyman Strong Spitzer, Jr. (1914–1997) and Ronald Richter (1909–1991) and Edward Teller (1908–2003)	Nuclear fusion investigation and start of experimentation. The process was in principle described by Hermann Ludwig Ferdinand von Helmholtz (1821–1894), but is continuously in action on the sun’s surface.		
1952	Donald Arthur Glaser (1926–2013)	Made the first bubble chamber. He was awarded the Nobel Prize in Physics in 1960. The first large-scale, terrestrial thermonuclear reaction was produced when a “hydrogen fusion device” was tested at Einewetok atoll on November 1.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.		
1956	Paul Winchell {Wilchinsky} (1922–2005)	Artificial heart (Jarvik 7).		
1957	USSR: Soviet Russia	Sputnik-1 [Russian: “Спúтник-1”]; first satellite.		
1957	Marvin Lee Minsky (1927–2016)	Confocal microscopy.		
1957	Herman P. Schwan (1915–2005)	Bioelectric impedance tomography (electric impedance tomography) and dielectric spectroscopy. Imaging mechanism based on the Maxwell–Wagner effect (polarization); based on the work of James Clerk Maxwell (1831–1879) and Karl Willy Wagner (1883–1953) in the early part of the twentieth century. The Maxwell–Wagner polarization mechanism, which reveals very large effective electric permittivity on scales larger than molecular size. The polarization can be artificially induced and has an associated specific (characteristic) relaxation time. <i>Note:</i> Herman Schwan (Schwann) is sometimes referred to as the “founding father of biomedical engineering.” One of the examples of bioelectric impedance tomography outside the use on humans is in the food industry. Impedance tomography is also used in geological investigation; geophysics application.		
1957+	David Edmund Kuhl (1929–), Luke Chapman (?), and Roy Edwards (?)	Positron emission tomography (PET).		
1971	Sir Godfrey Newbold Hounsfield (1919–2004) and respectively Allan MacLeod Cormack (1924–1998)	Computed tomography.		

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
1973	Paul Christian Lauterbur (1929–2007)	First operational MRI machine.		
1981	Gerd Binnig (1947–), Heinrich Rohrer (1933–)	Design of the scanning tunneling microscope (STM).		
1986	Gerd Binnig (1947), Heinrich Rohrer (1933–), Calvin Quate (1923–), and Christoph Gerber (1942–)	Initial concepts for the atomic force microscope (AFM) were introduced.		
1989	Paul K. Hansma (1946–), B. Drake (?), O. Marti (?), S.A. Gould (?), and C.B. Prater (?)	Scanning ion-conducting microscope. Imaging technique with close correlation to superconductivity.		
1990	Naohiro Tanno (?) and various groups with refinements by the MIT group consisting of David Huang (?), James G. Fujimoto (?), Carmen A. Puliafito (?), and others.	Optical coherence tomography (OCT).		
1961	Yuri Alekseyevich Gagarin [Russian: Юрий Алексеевич] (1934–1968); USSR: Soviet Russia	First space travel: Vostok spacecraft.		
1983	Collider Detector at Fermilab	World's first and at the time highest-energy particle accelerator, colliding antiprotons and protons propelled to center-of-mass energy reaching 2 TeV.		
2008	CERN, Switzerland	Large Hadron Collider, beginning of operations. To date no evidence supporting string theory or supersymmetry has been collected.		

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES		
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland.		

Material

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
6000 BC–2000 BC	Stone Age	Mechanical labor and tool fabrication
3300 BC–1000 BC	Bronze Age	Smelting and forging of soft metals using low heat: copper, tin, gold. This age also introduces the written documentation.
1000 BC–700 AD	Iron Age	Higher heat requirements and more detailed tool manufacturing, introducing scientific and engineering challenges. Historical tracking of processes and developments and philosophies. Introduction of complicated mechanisms and requiring detailed analytical thinking.
27 BC	Syria	Creation of glass.
400+	Italy	Lycurgus Cup, made with dichroic glass, consisting of early form nanoparticles. The cup shows a different color depending on whether illuminated from within or externally.
600	China	First documented production of ceramics.
1603	Sir Hugh Platt (1522–1608)	Hardening of metal.
1688	France	Construction of plate glass.
1774	Antoine Lavoisier (1743–1794)	Discovery of oxygen; and the chemical process of oxidation.
1782	Josiah Wedgwood (1730–1795)	Mass production of ceramic artifacts.
1811	Lorenzo Romano Amedeo Carlo Avogadro di Quaregna e di Cerreto, Count of Quaregna and Cerreto (1776–1856)	Molecular arrangements; molecular quantity in a mole of substance. Avogadro's law.
1821	Pierre Berthier (1782–1861)	Identification of the corrosion resistance properties for iron–chromium alloys; leading to stainless steel.
1836	Ignace Dubus-Bonnel ()	Introduction of a rudimentary form of fiberglass.
1839	William Hallows Miller (1801–1880)	Miller indices for lattice configuration, with specific applications to Bravais lattice structures.
1850	Auguste Bravais (1811–1863)	Uncovered lattice structure: Bravais lattice.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1855	Georges Audemars ()	Discovery of the process to produce rayon (cellulose nitrate); sometimes referred to as “artificial silk.”
1856	Sir Henry Bessemer (1813–1898)	Carbon steel.
1857	Michael Faraday (1791–1867)	Description of the unique optical properties for nanoparticles.
1874	Jacobus Henricus van't Hoff (1852–1911)	Introduction into the field of polymers.
1886	Friedrich Carl Zinoffsky (1830–??)	Determination of the polymer hemoglobin with molecular weight 16,700, following the work of Felix Hoppe-Seyler (1825–1895).
1887	Thomas Edison (1847–1931)	Advance ceramics processing technology.
1888	Wilhelm Roux (1850–1924)	Preliminary efforts leading to stem-cell research.
1901	Thomas Hunt Morgan (1866–1945)	Introduction of regenerative medicine, transplant research.
1902	Robert Williams Wood (1868–1955)	Surface plasmon resonance.
1906	Dmitri Ivanovich Mendeleev (1834–1907)	Periodic Table of Elements.
1908	William Henry Bragg (1862–1942) and William Lawrence Bragg (1890–1971)	Bragg diffraction law for crystalline lattice structures irradiated by X-ray radiation.
1908	Gustav Mie (1869–1957)	Scattering form nanoparticles, wavelength smaller than the scatter object size; Mie scatter.
1911	Heike Kamerlingh Onnes (1853–1926)	Discovery of superconductivity (metals).
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1916	Robert Andrews Millikan (1868–1953)	Experimentally verified Einstein's photoelectric equation.
1916	Peter Joseph Wilhelm Debye (Usa, 1884–1966), Paul Scherrer (B. 1890), next to Albert Wallace Hull (1880–1966)	Obtained the first experimental X-ray powder diffraction patterns.
1925	Wolfgang Ernst Pauli (1900–1958)	Pauli exclusion principle for atomic energy levels.
1929	Otto Stern (1888)	Obtained crystal diffraction of a beam of helium atoms.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1929	Wallace Hume Carothers (1896 – 1937)	Nylon discovered at Du Pont®.
1930	E. J. Williams () and William Lawrence Bragg (1890–1971)	Introduction of solid-state physics.
1931	Carl David Anderson (1905–1991)	Discovery of the positron, anti-particle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1934	Hideki Yukawa [湯川 秀樹], (1907–1981)	Introduction of mesons and the concept of antimatter.
1945	Dorothy Mary Hodgkin (1910–1994)	Protein crystallography, X-ray diffraction studies.
1947	George Dixon Rochester (1908–2001) and Clifford Charles Butler (1922–1999)	Introduction of the “strangeness” concept for quarks.
1953	Karl Ziegler (1898–1973)	Revolutionarized the process of polymerization, supporting mass production.
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович (Бенедиктович) Мигдаль] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.
1960		Introduction of the fiber-optic.
1961	James Edgar Till (1931–) and Ernest Armstrong McCulloch (1926–2011)	Stem cell research and forerunner of tissue engineering and regenerative medicine.
1965		Commercial development of the photovoltaic cell.
1965	Pierre-Gilles de Gennes (1932–2007)	Liquid crystal functionality.
1970	Sheldon Lee Glashow (1932–), John Iliopoulos (1940–), and Luciano Maiani (1941–)	Introduction of the charm quark.
1972	Stephen Hawking (1942–), Jacob Bekenstein (1947–2015)	Thermodynamics of black holes.
1974	Burton Richter (1931–) and Samuel Chao Chung Ting [Chinese: 丁肇中] (1936–)	Description of charm for the quark.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1975	Richard P. Blakemore ()	Magnetotactic bacteria.
1975	Claes-Göran Granqvist (1946–) and Robert A. Buhrman ()	Introduction of the concept and production of the first nanoparticles.
1975	Martin Lewis Perl (1927–2014)	Discovery of the tau lepton.
1977	Leon Max Ledderman (1922–)	Discovery of the “beauty” and “bottom” designation for quarks.
1978		Discovery of the “gluon” with the assistance of the PLUTO, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1980	Klaus von Klitzing (1943–)	Quantum Hall effect.
1987		Discovery of superconductivity in ceramic oxide, operating at higher temperature than metallic superconductors.
1991	Sumio Iijima [飯島 澄男] (1939–)	Discovery of carbon nanotube.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland. The Large Hadron Collider construction started in 1998 and produces particle acceleration with respective energy levels for protons at up to 4 teraelectronvolts (0.64 microjoules), or lead nuclei: 2.76 TeV per nucleon or 574 TeV per nucleus. The proton energy level was increased to 6.5 TeV in 2015.

Mechanics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 6000 BC	Egypt	First recorded drawings of rudimentary watercrafts.
ca 4000 BC	Eastern Europe	First recorded drawing of craft with rudimentary wheels.
4000 BC	Mesopotamia and Egypt	Documented recording of the construction of shelter, abandoning the nomadic structure.
ca. 3500 BC		First documented installation of sewer systems, primarily run-off.
ca. 3300 BC	Egypt	Drawings of sailboats.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
2700 BC–2500 BC	Egypt	Construction of pyramids, requiring advanced mechanical engineering efforts and architectural design (civil engineering).
ca. 1000 BC	Qanat aqueduct; Perzia	Water supply over a length greater than 71 km, and potential relation with sewer as a secondary use for liquid transport as part of the civil engineering efforts.
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Description of the “nature of objects.” Thales believed that objects are alive; part of the stream of thought by the “Hylozoists.”
430 BC	Socrates (470 BC–399 BC)	School of analytical thinking. Introduction to the base principles of what is currently considered classical mechanics.
350 BC	Aristotle (384 BC–322 BC)	Founder of the Lyceum school of analytical thinking in Macedonia. Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle proposed the concept of an external force (acting during flight) perpetuating the projectile motion of a ballistic object, however incorrect, apart from gravity forcing the object down.
ca. 250 BC	Archimedes (287 BC–212 BC)	Hand operated corkscrew water pump. The philosophies of Archimedes shaped the development process of modern engineering.
ca. 220 BC	China	Civil engineering effort of the architectural and mechanical design and construction of the Great Wall, Ming Dynasty.
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca. 80 BC–10 BC)	First recorded use and description of the mechanism-of-action of a steam-operated engine to perform work: Æolipile; described in <i>De Architectura</i> .
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεὺς] (10–70)	Second recorded use of steam to provide power to a machine; Æolipile.
650		First recorded use of wind mills and wind energy in the Persian Empire.
800	Persia, the Netherlands; detailed scientific documentation by Simon Stevin (1548–1620)	Wind energy used to pump water, windmill water pump: wind pump. Other use of the windmill was in manufacturing, for example, papermaking, cloth fabrication, wheat processing, and (much) later for the generation of electricity. Jan Adriaanszoon Leeghwater [Leechwater] (1575–1650); draining a significant area of land north from Amsterdam to make it habitable in 1612 (son of carpenter Adriaan Symonszoon [–1618]).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
900–1200	Mexico, central America	Construction of temples, which apparently have a close correlation to astronomical observations. Civil engineering.
1206	Al-Jazari (1136–1206) [Turkey]; Badi'al-Zaman Abū al-'Izz ibn Ismā'il ibn al-Razāz al-Jazarī (Arab: <i>بْنُ الْعِزِّ أَبُو الزَّمَانِ بَدِيعُ الْجَزَرِيِّ الرَّزَازُ بْنُ إِسْمَاعِيلَ</i>)	Publication of <i>Book of Knowledge of Ingenious Mechanical Devices</i> . Description of mechanical devices and mechanism of action.
1245	Thomas Aquinas (1225–1274)	Reformulation of the dynamic concepts of Aristotle (384 BC–322 BC).
1500	Leonardo da Vinci (1452–1519)	Formal description of physical phenomena based on the state-of-the-art mathematical definitions. Description of several machines, including “flying machines,” and a rudimentary theoretical discourse on the respective mechanism of action for several dynamic systems.
1600	William Gilbert (1544–1603)	Publication about events and scientific exploration of earth's phenomena: <i>Terrella</i> . Additional work was on the description of the magnetic field and magnet in <i>De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure</i> .
1617	Johannes Kepler (1571–1630)	Kepler's third law of planetary motion, based on the collected data by Tycho Brahe (1546–1601).
1623	Galileo Galilei (1564–1642)	Experimentation; experimental design, publication: ‘Il saggiaiore’ (<i>The Assayer; Mechanics</i>). Galileo described the influence of air as a resistive force in comparison to water for the first time. First principles of mechanics: description of laws of motion (falling bodies; gravitational acceleration), projectile motion (ballistics), and inertia, before Sir Isaac Newton (1643–1727). Invented the pendulum clock and many more engineering feats. By some considered the father of mechanics.
1640	Francesco Maria Grimaldi (1618–1663)	Documentation that the fall of an object traverses a distance that is proportional to the square of the elapsed time, linking it to the gravitational acceleration. Collaborations with Giovanni Battista Riccioli (1598–1671).
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases.
1673	Christiaan Huygens (1629–1695)	Huygens introduced several concepts of mechanical engineering and described the mechanism of shock waves.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
ca. 1666	Sir Isaac Newton (1643–1727)	Sir Isaac Newton introduced several laws of motion: Newton's three laws of motion. This forms the macroscopic scale of the field of classical mechanics. The publication of the <i>Philosophiæ Naturalis Principia Mathematica</i> in 1685 provides detailed definitions regarding ballistic motion, circular motion (centripetal force), laws of action–reaction, gravitational acceleration, inertia, and force with respect to acceleration. Sir Isaac Newton derived the inverse square law for gravitational force in 1666. Formal introduction of the field of classical mechanics.
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine.
1712	Thomas Newcomen (1664–1729)	Construction of a “atmospheric” steam engine.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
	Leonard Euler (1707–1783)	Contributions to the mechanical aspects of civil engineering. Leonard Euler provided a mathematical recourse of the load applied to columns (architecture) and the associated buckling under excessive forces.
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam-powered automobile, the predecessor to the internal combustion automobile.
1807	Thomas Young (1773–1829)	Formal introduction of the Young's modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783).
1830	Joseph Henry (1797–1878)	First electromotor constructed.
1851	Sir George Gabriel Stokes, 1st Baronet (1819–1903)	Creeping flow, partially applicable to seismology. Specific seismic work of Gabriel Stokes was on a human size scale, describing vibrational forces and energy related to driven oscillations while crossing bridges, and the resulting bridge collapses in his days. One of the fall-out from the bridge vibration and collapse is development of studies in metal fatigue.
1877	Ludwig Eduard Boltzmann (1844–1906)	Introduction of the field of statistical mechanics; discrete energy levels. This formed the formal introduction to quantum mechanics. Publication of the paper “On the Relation of a General Mechanical Theorem to the Second Law of Thermodynamics.”
1880	Paul-Jacques Curie (1855–1941) and Pierre Curie (1859–1906)	Discovery of electric charges emerging on the surfaces of crystals that are subjected to shear or normal stress. This is referred to as the piezoelectric effect.
1892	Jules Henri Poincaré (1854–1912)	Celestial mechanics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube. Joseph Thompson describes the atom as a “plum pudding” where the raisins in the spherical blob are the electrons.
1900	Max Karl Ernst Ludwig Planck (1858–1947)	Introduction of the premise of quantum theory. The energy of electromagnetic radiation is proportional to the frequency of the electromagnetic wave; discrete quanta with respect to the narrow wavelength bandwidth.
1902	Josiah Willard Gibbs (1839–1903)	Publication of his book <i>Elementary Principles of Statistical Mechanics</i> .
1905	Albert Einstein (1879–1955)	Introduction of special theory of relativity.
1909	Robert Andrews Millikan (1868–1953)	Measurement of the mass of the electron.
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure definition (Bohr atomic model) and introduction to quantum theory.
1917	Ernest Rutherford, 1st Baron Rutherford of Nelson (1871–1937)	Discovery of the proton.
1920	Amalie (Emmy) Noether (1882–1935)	Theoretical connection between symmetry and conservation laws. Emmy Noether made significant contributions to a broad field of mathematical applications and the theoretical description of physics concepts. Noether worked closely with David Hilbert (1862–1943) in the early part of her career. Noether introduced two statements, the first regarded as Noether's first theorem, treating conservation laws in a manner of a stress energy tensor, posing that there is a corresponding conservation law corresponding to every differentiable symmetry of the action associated with the physical system. The Noether conservation theorem applies directly to quantum mechanics. Noether's second theorem links the symmetry of an action function for a system to the system's differential equations. The action in this case is an integral defined by the Lagrangian function, from which the behavior of the system can be derived based on the “principles of least action.”
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all objects in motion. Matter wave, propagating with the de Broglie wavelength.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1925	Sir William Hamilton (1788–1856), David Hilbert (1862–1943), Max Planck (1858–1947), Albert Einstein (1879–1955), Niels Bohr (1885–1962), Werner Heisenberg (1901–1976), Louis de Broglie (1892–1987), Erwin Schrödinger (1887–1961), Pascual Jordan (1902–1980), Max Born (1882–1970), Wolfgang Pauli (1900–1958), Paul Dirac (1902–1984), John Wheeler (1911–2008), and John von Neumann (1903–1957)	Introduction of the field of quantum mechanics, the list may be extended, however the main contributors are listed. Quantum mechanics is the field of mechanics, a branch of physics, describing events on a nanoscopic scale, based on the realization that the energy distribution for a system does not always form a continuous spectrum. The work of Erwin Schrödinger (1887–1961) combined quantum mechanics with special relativity, forming a subsection of wave mechanics.
1926	1928: Paul Dirac (1902–1984); 1929 Dmitri Vladimirovich Skobeltsyn (1892–1990); 1932 Carl David Anderson (1905–1991)	Discovery of positron. Generally Carl Anderson is credited with the formal discovery (Nobel Prize).
1926	Jean Baptiste Perrin (1870–1942)	Physical proof providing the existence of molecules.
1927	Wolfgang Ernst Pauli (1900–1958) Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles.
1932	James Chadwick (1891–1974)	Discovery of the neutron.
1941	Richard Phillips Feynman (1918–1988)	Amplitude formulation of the principles of quantum mechanics under the Laplacian approach, or “many paths approach,” with equivalence to the “least action” theorem. In principle this combines the matrix formulation and the wave formulation.

Meteorology

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
3000 BC	India	Description of seasonal cycles and cloud formations, and rudimentary reference to the earth's movement around the sun.
ca. 600 BC	China; India	Documented use of magnetic compasses; the lodestone. More specific documented use dates to the Han Dynasty (ca. 206 BC).
ca. 600 BC	Thales of Miletus (ca. 624 BC–ca. 546 BC; known as Thales: Θαλῆς)	Introduction of metrology, accurate measurements of objects, phenomena, events, and conditions (e.g., atmospheric conditions).
430 BC	Democritus (of Greece) (460 BC–370 BC)	Rudimentary weather prediction processes.
430 BC	Hippocrates of Chios (ca. 470–410 BC)	Publication of the seasonal variabilities and wind velocity and direction profiles.
350 BC	Aristotle (384 BC–322 BC)	Aristotle described the initial concepts of physics, motion, time as well as astronomy concepts. Aristotle used geological and atmospheric record keeping for the prediction of weather conditions (meteorology). First documented use of a scientific approach to weather forecasting.
ca. 250 BC	Archimedes (287 BC–212 BC)	Revealed the properties that define buoyancy. The base principles relate to the tectonic plate mechanics.
50	Gaius Plinius Secundus (23–79), known as: Pliny the Elder	Publication of the magnetic action of the lodestone in his publication: <i>Naturalis Historia</i> . A rather detailed description of the use of magnetism for geographical location determination is described.
62	Hero of Alexandria [ἥρων δ' Ἀλεξανδρεὺς] (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. The base of this methodology formed the principle understanding of the movement of atmospheric air masses in future years.
82	Wang Chong (27–97)	Description of the formation of rain as the result of condensed water vapor (clouds), in contrast to an “extraterrestrial” cause.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
120	Claudius Ptolemy {Ptolemaeus} [Πτολεμαῖος] (90–168)	Geographic recordings of a significant part of the Islamic and western world (i.e., Roman and Persian Empire), living in Egypt, as a Roman with Greek education. His cartography extended all the way out, including parts of China (discovered in fifteenth century). He specifically developed arithmetical techniques for calculating astronomical phenomena, under the teachings of Babylonian astronomers. Also known as: بطليموس (Batlaymus; Arabic). Combining the cartography with the ancient Chinese knowledge of the earth's magnetic field formed early recording of the location of the North and South pole, however rudimentary, only a portion of the earth had been mapped. Later documentation with a detailed world map provided an indication of the migration of the magnetic poles.
500	Varahamihira (505–587) [Devanagari: वराहमिहिर]	Detailed meteorological discourse describing atmospheric events: “Brihatsamhita.”
600	Isidore de Seville (560–636)	Description of rainbows, clouds, wind, and rain.
850	Al-Kindi (Alkindus) [Abu Yūsuf Ya‘qūb ibn ’Ishāq aṣ-Ṣabbāḥ al-Kindī (Arabic: بن يعقوب يوسف أبو الكندي الصباح إسحاق) (801–873)	Description of flow of natural media and a misconceived interpretation that the tides in the oceans are caused as the result of temperature effects, which does apply to the flow of air.
1021	Ibn al-Haytham (Alhazen) [Abū ‘Alī al-Ḥ- asan ibn al-Ḥasan ibn al-Haytham (Arabic: بن الحسن ، علي أبو الهيثم بن الحسن) (965–1040)	Description of the refraction of light during sunset and sunrise causing the discoloration of the sky. Alhazen uses geometry and his refraction theory to calculate the height of “earth’s atmosphere,” yielding approximately 80 km, which is close to the currently accepted average altitude of the mesosphere of 80 km.
1027	Avicenna [Arabic: ابن الحسين علي أبو [سينا ابن الله عبيد (ca. 980–1037)	In his <i>Book of Healing</i> there is a description of meteorology, how mountains influence the formation of clouds and weather conditions. Additional information about earthquakes and description of a meteor.
1050		Full-scale use of the compass for geographical orientation.
1121	Abu Jafar Muhammad ibn Hasan Khazini (900–971)	Study of the hydrostatic balance.
ca. 1240	Albert the Great (1193–1290)	Description of the refraction of light by an individual raindrop, hence deriving that the rainbow must be produced by little drops of air in the sky.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1269	Petrus Peregrinus of Maricourt	Formal description of the use of the compass during seafaring expeditions.
1441	Prince Munjong of Josen (1414–1452)	Description of the introduction and use of a standardized rain gauge in Korea. The rain gauge served as a tool to estimate the cross yield and from this the tax base was determined.
1450	Leone Battista Alberti (1404–1472)	First conceptual anemometer, the swinging plate wind velocity meter.
1450	Nicolas Cryfts (Nicolas of Cusa) (1401–1464)	Design and experimental verification of the hair hygrometer for the measurement of the humidity. This design is still used, next to other new technology.
1494	Christopher Columbus (1451–1506)	Description of the first experience with a cyclone; encounters with hurricane on the shores of the “Americas.”
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man,” involved in all aspects of cultural evolution, science, engineering, politics, and art. Drawing of the design of the first hair hygrometer in his <i>da Vinci's Codex Atlanticus</i> . The design was created and tested in 1450 by Nicolas Cryfts (Nicolas of Cusa) (1401–1464).
1543	Nicolaus Copernicus (1473–1543); alias of Niclas Koppernigk	Introduction of the heliocentric model for the earth, sun, and close planets. This follows the statement by the astronomer from Greece: Aristarchus of Samos (ca. 310–ca. 230 BC), made more than 1700 years prior. The scientific observations made by Copernicus were validated by Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Regulate the general scientific methodology.
ca. 1600	William Gilbert (1544–1603)	Experimentalist. Description of magnetism, in his work <i>De magnete, magnetisque corporibus, et de magno magnete tellure</i> . The compass had been in use since 206 BC (Chinese Han Dynasty: 206 BC–220 AD; maybe even earlier, during the Qin Dynasty: 221 BC–207 BC), in the European and Persian area since the thirteenth century.
ca. 1600	Galileo Galilei (1564–1642)	Major contributor to the scientific revolution and the (re) introduction of analytical thinking in science, engineering, and general thought processes. Galileo Galilei was remanded under house arrest by the Roman Inquisition for his views and teachings where he died after 9 years. This was the trailing end of the Renaissance period.
1611	Johannes Kepler (1571–1630)	Description of the “snow-flake.”

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits. Vortices are found in geological phenomena such as cyclones (hurricanes), maelstrom, and aspects of magma flow.
1632	Evangelista Torricelli (1608–1647)	Introduction of the barometer; essential in weather prediction; meteorology.
1650	Blaise Pascal (1623–1662)	Pascal's law, pressure in a container applies an equal force on all surface of the enclosure. The unit for pressure under atmospheric conditions uses the unit Pascal in his honor.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior of gases. Boyle mentioned the compression of gas relating to partial pressure of atmospheric constituents and barometric values.
1662	Sir Christopher Wren (1632–1723)	First documented use of rain gauge.
1679	Denis Papin (1647–ca. 1712)	Pressure and thermodynamic and mechanical impacts. Denis Papin worked as an assistant to both Christiaan Huygens (1629–1695) and Robert Boyle (1627–1691). His invention of the pressure cooker bears some resemblance to the conditions found in geysers.
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring.
1686	Edmund Halley (1656–1742)	Study of the cause-and-effect relationship between solar heating and the occurrence of monsoon and trade winds. This work ties to the atmospheric motion. Edmund Halley also described the relationship he found between the measured atmospheric pressure and the observation altitude with respect to the sea level.
ca. 1687	Sir Isaac Newton (1643–1727)	The recognition of gravitational force provided one of the essential building blocks in the geological understanding next to cartography and the physical description of location-specific meteorologic phenomena.
1750–1800		With the advent of more sophisticated measurement instrumentation (thermometer, barometer, wind velocity meter) meteorology became more scientifically rooted, especially with the interest of a broad range of mathematicians in the dynamics of physics; thermodynamics, motion, wave propagation, and pressure perturbations. The methodology for cartography and for geographic orientation (compass) also had evolved significantly.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1732	Anders Celsius (1701–1744)	Thermometer-scale calibration based on pure water phases.
1733	Daniel Bernoulli (1700–1782)	Acoustics, mechanical vibrations, and fluid dynamic principles introduced. Definition of the fundamental frequency and higher harmonics, with supporting elaborate mathematical analysis (solutions to differential equations). This laid the foundation for seismic imaging using P-wave (primary wave; longitudinal) and S-wave (secondary wave, or shear wave [transverse]).
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases.
1743	Jean-Baptiste le Rond d'Alembert (1717–1783)	Publication on the concepts of forces and accelerating systems: <i>Traite de Dynamique</i> .
1749	Alexander White (1714–1786) and Thomas Meville (seventeenth century)	Atmospheric data collection by means of weather balloons, replacing the use of kites.
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current” associated with lightning bolts.
1780	Charles Theodore, Prince-Elector, Count Palatine and Duke of Bavaria (1724–1799)	Introduction of an international network of meteorologic observation stations: <i>Societas Meteorologica Palatina</i> .
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days. The meteorological implications extend out to the influence of lightning on the environmental conditions: specifically the formation of ozone.
1783	Antoine Laurent de Lavoisier (1743–1794)	Discovery of oxygen and the chemical impact.
1785	Jacques Alexandre César Charles (1746–1823)	Charles's law, expansion of gases.
1802	Luke Howard (1772–1864)	Introduction of the nomenclature for cloud formations.
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.
1822	Jean-Baptiste Joseph Fourier (1768–1830)	Introduction of the use of dimensions in mathematical solution and definition of physical quantities.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Introduction to the second law of thermodynamics, with heat exchange implications providing explanation to natural phenomena.
1827	Robert Brown (1773–1858)	Brownian motion.
1835	Gaspard-Gustave de Coriolis (1792–1843)	Influence of the earth's rotation on the flow movement and direction: Coriolis force.
1840	Jean Léonard Marie Poiseuille (1799–1869) and Gotthilf Heinrich Ludwig Hagen (1797–1884)	Pressure drop for incompressible fluids with respect to laminar flow. Reference to meteorology, wind formation based on arctic versus topical pressure systems.
1843–1848	James Prescott Joule (1818–1889)	Empirical verification of the first law of thermodynamics: stating the equivalence of heat and work. This applies to both the source energy for the persisting liquid core (magma) and the work performed by volcanic eruptions and earthquakes.
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin. Reference base for geological events and meteorology.
1850	Rudolf Julius Emanuel Clausius (1822–1888)	Recognition of two basic principles of thermodynamics, later introduced by means of the first and second law of thermodynamics, respectively: energy is constant and entropy tends toward a maximum. Clausius introduced the parameter U , representing the internal energy. Publication of book <i>On the Motive Power of Heat, and on the Laws Which Can Be Deduced from It for the Theory of Heat</i> . Clausius introduced what is now regarded the second law of thermodynamics in 1865 (referred to by William John Macquorn Rankine [1820–1872] as the “thermodynamic function”), as part of any natural thermodynamic process, the sum of the entropies of the participating systems will increase. The heat exchange applies directly to solar heating and the formation of weather (and environmental) conditions.
1851	Jean Bernard Léon Foucault (1819–1868)	Foucault pendulum, illustrating the impact of the earth's rotation on motion.
1851	Sir George Gabriel Stokes, 1st Baronet (1819–1903)	Creeping flow, partially applicable to air stream Furthermore, the work of Stokes contributed to the development of the scientific and engineering support for the construction of high-rise buildings in earthquake-prone geographical regions.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule–Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid, or liquid. Sometimes also found as the Joule–Kelvin effect. Cloud formation and the release of rain and snow fall under this topic. The Joule–Thomson effect is an isenthalpic process, which entails that the enthalpy of the fluid is constant during the process, which applies to Joule–Thomson inversion temperature, described in the Linde cycle (Carl von Linde [1842–1934]), offering conditions leading to cloud formation.
1859	James Clerk Maxwell (1831–1879)	Description of the distribution law of molecular velocities; also applies to atmospheric conditions.
1868	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907) and Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Kelvin–Helmholtz wave phenomenon (Kelvin–Helmholtz instability), resulting from a velocity shear in a moving single continuous fluid or at the interface between two fluids. The two fluids may be the same medium at different temperature and hence different respective density. Described separately by Lord Kelvin (1871) and Hermann von Helmholtz (1868). This phenomenon is most clearly observable for rolling cloud formations, but is also experienced in deep water (ocean), the corona of the sun, and applies to Jupiter’s “red spot.”
1873	James Clerk Maxwell (1831–1879)	Theory of electromagnetic radiation: <i>Treatise on Electricity and Magnetism</i> . James Maxwell made use of the prior work by Wilhelm Eduard Weber (1804–1891) and Johann Carl Friedrich Gauss {Gauß} (1777–1855). Solar radiation heats the earth’s surface causing gradients in temperature or discontinuities resulting in the movement of air masses, next to local temperature sensation.
1876	Josiah Willard Gibbs (1839–1903)	Chemical potential, an energy constituent within the Gibbs free energy, setting the standard for the energy content and exchange with respect to phase transitions. Thermodynamic concept describing the energy that can be released or absorbed during a chemical process.
1900	Ludwig Eduard Boltzmann (1844–1906)	Thermodynamic concepts with respect to heat exchange in the earth’s volume, specifically defining the entropy. Boltzmann equation for statistical mechanics, introduced by Ludwig Boltzmann between 1872 and 1875, reformulated by Max Karl Ernst Ludwig Planck (1858–1947). For certain systems also addressed as the Gibbs entropy formula, after Josiah Willard Gibbs (1839–1903).
1902	Philippe Teisserenc de Bort (1855–1913)	Description of several of the earth’s atmospheric layers: stratosphere, tropopause, and troposphere. Additional credit for the outline of the lower part of the atmosphere goes to Richard Assmann (1845–1918).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1903	Vagn Walfrid Ekman (1874–1954)	Discovery of layered structure of the ocean waters, in similar arrangement as the earth's atmosphere.
1904	Vilhelm Friman Koren Bjerknes (1862–1951)	Introduction of the mathematical modeling requirements for weather prediction.
1905	Albert Einstein (1879–1955)	Recognition and description of the mesosphere.
1912	Theodore von Kármán (1881–1963)	Description of the “von Kármán vortex street.” Turbulent flow profile, first observed and described by Arnulph Henry Reginald Mallock (1851–1933) and also by Henri Claude Bénard, (1874–1939)
1917	Sir Horace Lamb (1849–1934)	Introduction of the concept of evanescent waves, referred to as Lamb waves. Elastic waves traveling between two superimposed layers: inversion surface, a third layer forcing itself between the two stacked layers. The resulting compression and extension provides a line pattern of cloud formation, formed in the low-pressure parts of the wave pattern; expanding air forms condensation. Also known as “morning glories.”
1922	Jacob Aall Bonnevie Bjerknes (1897–1975), Vilhelm Friman Koren Bjerknes (1862–1951), Halvor Skappel Solberg (1895–1974) and Tor Bergeron (1891–1977)	Formulation of pressure fronts and the general movement of air masses.
1926	John Patterson (1872–1956)	Three cup anemometer, improvement on the work of Leone Battista Alberti (1404–1472).
1938	Guy Stewart Callendar (1898–1964)	Description of the concept of global warming resulting from the insulating layer of carbon dioxide exhaust in the atmosphere.
1941		Introduction of “pulse radar” used for the localization and determination of the geographical extend of precipitation.
1960		Launch of the first weather satellite.
1971	Tetsuya Theodore “Ted” Fujita [藤田 哲也] (1920–1998)	Introduction of the Fujita scale to quantify the magnitude of tornadoes, cyclones, hurricanes, and typhoons.
1994	Andreas Pflietsch (1958–)	Sonic anemometer.
1995	Roger Lee Easton (1921–2014)	Development of the global positioning concept (GPS).

Nuclear

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
13.8 billion years BC	Georges Henri Joseph Édouard Lemaître (1894–1966) and Edwin Powell Hubble (1889–1953)	“The Big Bang”; In 1927 the expanding universe was recognized.
350 BC	Aristotle (384 BC–322 BC)	The word “energy” has the Greek origin “Enérgeia” [Greek: ἐνέργεια], which was documented by Aristotle, “enérgeia” does not translation directly into English, the meaning resembles “being at work.”
ca. 1800	John Dalton (1766–1844)	Introduction of the “law of multiple proportions” describing the atomic concept based on chemical reactions taking place in ratios of small whole numbers.
1870	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Unofficial introduction to the mechanism of action for nuclear fusion.
1896	Wilhelm Conrad Röntgen (1845–1923)	Discovery of X-ray radiation.
1896	Henri Becquerel (1852–1908)	Emission of “Becquerel rays” from uranium salts, later identified as alpha particles. Becquerel already recognized that this emission was different from X-ray since it was deflected by means of an applied external magnetic field. Conceptual introduction to the field of radioactivity.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes’s vacuum tube.
1897	Marie Skłodowska-Curie (1867–1934)	Discovery of radioactive isotopes. Marie Curie introduced the term “radioactivity.”
1899	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Emission of alpha particle.
1900	Max Karl Ernst Ludwig Planck (1858–1947) and James Clerk Maxwell (1831–1879)	Formal description of the photon and the energy associated with the electromagnetic wave.
1903	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Discovery of the nuclear decay half-life.
1903	Marie Skłodowska-Curie (1867–1934) and Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Quantification of nuclear decay.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1906	Dmitri Ivanovich Mendeleev (1834–1907)	Periodic Table of Elements.
1908	Johannes Geiger (1822–1945) and Ernest Rutherford (1871–1937)	Development of the Geiger counter, used to measure radioactive radiation.
1909	Francis Aston (1877–1945)	Mass spectrometer mass separation of closely separated isotopes. Highly sensitive mass spectrometer design.
1911	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Rutherford scattering on nuclear level, indication of the existence of the proton. The proton itself was not mentioned until 1932, this time again by Ernest Rutherford.
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1913	Frederick Soddy (1877–1956)	Formal introduction of the isotope concept.
1914	Niels Henrik David Bohr (1885–1962)	Description of the atomic energy layer model; hydrogen (Bohr atomic model).
1915	Sir Ernest Marsden (1889–1970)	Artificial transmutation, associated with radon enclosed by vacuum.
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. Nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.
1919	Ernest Rutherford (1871–1937)	Artificial transmutation, hydrogen formation resulting from collisions of alpha particles with nitrogen, also generating oxygen and gamma rays.
1923	Arthur Holly Compton (1892–1962)	Description of the deflection of photons by a charge unit, generally an electron, potentially the nucleus: Compton effect.
~1925		Recognition of the “Coulomb barrier” in nuclear collision, providing a “tunneling” effect for the release of alpha particles.
1927	Werner Karl Heisenberg (1901–1976)	Quantum uncertainty principle.
1927	Paul Adrien Maurice Dirac (1902–1984)	Description of antimatter.
1928	Johannes Geiger (1822–1945) and Walther Müller (1905–1979)	Introduction of an improved Geiger counter: the Geiger–Müller counter, using ionization of a confined gas.
1931	Wolfgang Ernst Pauli (1900–1958)	Theoretical introduction of the neutrino. The experimental verification of the existence of the neutrino was not until 1956 by Frederick Reines (1918–1998) and Clyde Cowan, Jr. (1919–1974).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1931	Carl David Anderson (1905–1991)	Discovery of the positron, antiparticle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1932	Sir James Chadwick (1891–1974)	Discovery of the neutron. Student of Ernest Rutherford (1871–1937).
1934	Leo Szilard (1898–1964)	Recognition of nuclear decay chain reactions.
1934	Hideki Yukawa [湯川 秀樹], (1907–1981)	Introduction of mesons and the concept of antimatter.
1934	Ida Noddack (1896–1978)	Formal introduction of the concept of “fission,” however not recognized by her peers at the time. The fission phenomenon was only recognized when announced by Enrico Fermi (1901–1954) later that year.
1934	Enrico Fermi (1901–1954)	Interaction of slow neutron with nuclei and the resulting decay into different elements, including aluminum and uranium.
1935	Arthur Dempster (1886–1950)	Discovery of the lighter uranium isotope: uranium-235.
1936	Otto Hahn (1879–1968) and Lise Meitner (1878–1968)	Neutron collision of uranium-induced decay examination.
1937	Carl David Anderson (1905–1991), Seth Henry Neddermeyer (1907–1988), Jabez Curry Street (1906–1989), and Edward C. Stevenson ()	Confirmation of the existence of the meson, and muon.
1938	Niels Henrik David Bohr (1885–1962) and John Archibald Wheeler (1911–2008)	Formal description of the nuclear fission process.
1939	J. M. B. Kellogg	Discovery of a finite quadruple moment for the deuteron, requiring a noncentral (tensor) nuclear force configuration.
1940	Otto Robert Frisch (1904–1979)	Development of the detonation mechanism for the first atomic bomb.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more.
1947	George Dixon Rochester (1908–2001), Clifford Charles Butler (1922–1999)	Discovery of the subatomic particle: the “kaon,” k-meson. Introduction of the “strangeness” concept for quarks, although the quark concept had not been introduced. In the elementary particle phenomenology the kaon is a bound state of an up- or down quark with a strange quark (antiquark).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1947	Maria Goeppert-Mayer (Göppert) (1906–1972)	Theoretical concept development for the understanding of nuclear forces, based on a shell model, similar to the atomic electron model.
1947	William Webster Hansen (1909–1949)	Linear accelerator installation at Stanford University, California.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model for atomic nuclei.
ca. 1952	Ludwig von Helmholtz (1821–1894), Lyman Strong Spitzer, Jr. (1914–1997), and Ronald Richter (1909–1991) and Edward Teller (1908–2003)	Nuclear fusion investigation and start of experimentation. The process was in principle described by Hermann Ludwig Ferdinand von Helmholtz (1821–1894), but is continuously in action at the sun's surface.
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.
1956	Frederick Reines (1918–1998) and Clyde Lorrain Cowan, Jr. (1919–1974)	Experimental confirmation of the neutrino introduced in 1931 by Wolfgang Pauli (1900–1958).
1958	Stanley Mandelstam (1928–2016)	Introduction of Mandelstam variables associated with the concept of “crossing symmetry,” defining numerical quantities, which encode the energy, momentum, and scattering angles of particles in a deflection process described in a Lorentz-invariant fashion.
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович (Бенедиктович) Мигдаль] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.
1961	Murray Gell-Mann (1929–)	Description of elementary particles, eightfold way of defining “strangeness” for the quark. Formal introduction of the elementary particle “quark” concept, the building blocks for protons and neutrons. The “quark” name is based on an expression in the book <i>Finnegans Wake</i> by James Joyce.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Николай Геннадиевич Басов] (1922–2001) and Aleksandr Mikhailovich Prokhorov [Александр Михайлович Прохоров] (1916–2002)	Quantum electronics.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1970	Sheldon Lee Glashow (1932–), John Iliopoulos (1940–), and Luciano Maiani (1941–)	Introduction of the charm quark.
1974	Burton Richter (1931–) and Samuel Chao Chung Ting [Chinese: 丁肇中] (1936–)	Description of charm for the quark.
1975	Martin Lewis Perl (1927–2014)	Discovery of the tau lepton.
1977	Leon Max Ledderman (1922–)	Discovery of the “beauty” and “bottom” designation for quarks.
1978		Discovery of the “gluon” with the assistance of the PLUTO, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1983	Collider Detector at Fermilab	World’s first and at the time highest-energy particle accelerator, colliding antiprotons and protons propelled to center-of-mass energy reaching 2 TeV.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
2012	François Baron Englert (1932–) and Peter Ware Higgs (1929–)	Higgs boson (126 GeV) discovery in the Large Hadron Collider at CERN, Geneva, Switzerland. The Large Hadron Collider construction started in 1998 and produces particle acceleration with respective energy levels for protons at up to 4 teraelectronvolts (0.64 microjoules), or lead nuclei: 2.76 TeV per nucleon or 574 TeV per nucleus. The proton energy level was increased to 6.5 TeV in 2015.

Optics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~300 BC	Euclid (of Alexandria) (323 BC–283 BC)	Description that light travels in straight lines and defines his version of the law of reflection in his publication: <i>Optica</i> . Euclid was a proponent of “extramission for vision; believed that vision involves rays going from the eyes to the object observed. Euclid also described the relationship between the apparent sizes of objects and the angles with the optical axis of the eye: angular magnification.
~150 BC–100 BC	Hero (also known as Heron) of Alexandria (10–70)	Hero showed, by a geometrical means, how the actual path outlined by a ray of light reflected from a plane mirror is shorter than any respective other path resulting from reflected that might be drawn between the source and the chosen point of observation, publication <i>Catoptrica</i> .

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~140 AD	Claudius Ptolemy (ca. 100–ca. 168)	In a translation from an Arabic publication assumed to be by Ptolemy in the twelfth century into Latin Ptolemy presents a study of refraction, which continues to describe the phenomena of atmospheric refraction. He suggested that the angle of refraction at the interface of two media is proportional to the angle of incidence.
1021	Abū ‘Alī al-Ḥasan ibn al-Ḥasan ibn al-Ḥaytham [Arabic: الحسن بن الحسن، علي أبو الهيثم بن], Alhazen (ca. 965–1040)	First documented recognition of the refraction mechanism of action. In his investigations, Alhazen used spherical and parabolic mirrors and was aware of spherical aberration. He also investigated the magnification produced by lenses and atmospheric refraction. His work was translated into Latin and became accessible to later European scholars. Publication: “Risala fi l-Daw” (<i>Treatise on Light</i>) as a supplement to his <i>Book of Optics</i> . He discusses the meteorology of the rainbow, the density of the atmosphere, and various celestial phenomena, including the eclipse, twilight, and moonlight.
1088	Shen Kuo or Shen Gua [Chinese: 沈括] (1031–1095)	In his Dream Pool Essays (梦溪笔谈) a vivid descriptions of tornadoes, that rainbows were formed by the shadow of the sun in rain, occurring when the sun would shine upon it, and the curious common phenomena of the effect of lightning that, when striking a house, would merely scorch the walls a bit but completely melt to liquid all metal objects inside.
~1220	Robert Grosseteste (1175–1253)	Magister scholarum of the University of Oxford and a proponent of the view that theory should be compared with observation, Grosseteste considered that the properties of light have particular significance in natural philosophy and stressed the importance of mathematics and geometry in their study. He believed that colors are related to intensity and that they extend from white to black, white being the purest and lying beyond red with black lying below blue. The rainbow was conjectured to be a consequence of reflection and refraction of sunlight by layers in a “watery cloud” but the effect of individual droplets was not considered. He held the view, shared by the earlier Greeks, that vision involves emanations from the eye to the object perceived.
ca. 1240	Albert the Great (1193–1290)	Description of the refraction of light by an individual raindrop, hence deriving that the rainbow must be produced by little drops of air in the sky.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
~1267	Roger Bacon (1214–1294)	Roger Bacon was a follower of Robert Grosseteste (1175–1253) at Oxford. Bacon elaborated on Grosseteste's work on optics. He concluded that the speed of light is finite and its propagation is similar to the propagation of sound. In his publication <i>Opus Maius</i> , Bacon provides a description of the magnification of small objects by means of rudimentary convex lenses and suggested that the use of external lenses could find application in the correcting defective eyesight. He also recognized the formation of the rainbow due to “reflection” of sunlight from (within) individual raindrops.
~1270	Witelo (ca. 1220–ca. 1278)	Compilation of a standard text on optics: <i>Perspectiva</i> , to be used for several centuries. Witelo published a method of machining parabolic mirrors from iron. Witelo also performed and documented observations on refraction. He recognized that the angle of refraction is not equal to the angle of incidence, however he did not report any observation of total internal reflection.
1303	Bernard de Gordon (1270–1330)	A physician, he mentioned the use of spectacles as a way of correcting far-sightedness (hyperopia).
1304–1310	Theodoric (Dietrich) of Freiberg (1250–1310)	Theodoric explained the formation of a rainbow as the result of refraction and internal reflection within individual raindrops. He provided a detailed explanation for the appearance of a primary and secondary rainbow but, following earlier established belief and scientific interpretations, he considered color to rise from a combination of different proportions of darkness and brightness.
1558	Giambattista della Porta (1535–1615)	Incorporation of a lens in the opening of a camera obscura significantly improved the image formation capabilities.
~1590	Zacharius Janssen (1585–1632)	Constructed a compound microscope with a converging objective lens and a diverging eye lens.
1604	Johannes Kepler (1571–1630)	Suggestion that the radiant intensity (radiance) of light from a point source varies inversely with the square of the distance from the source in his book <i>Ad Vitellionem Paralipomena</i> . Introduction of the notion that light can be propagated over an unlimited distance and that the velocity of light propagation is supposedly infinite. Kepler also described vision as a consequence of the formation of an image on the retina resulting from light passing through the lens in the eye, and additionally correctly described the causes of “far-sightedness” (hyperopia) and “near-sightedness” (presbyopia).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1604	Johannes Kepler (1571–1630)	Formal introduction of the term “camera obscura.”
1608	Hans Lippershey (1570–1619)	Construction of a telescope based on a converging objective lens and a diverging ocular lens configuration.
1609	Galileo Galilei (1564–1642)	Constructed his own version of the telescope design introduced by Hans Lippershey (1570–1619) and used it for astronomical observations.
1610	Galileo Galilei (1564–1642)	Using his telescope, Galileo reported a broad scale of astronomical discoveries including the four (4) moons of Jupiter.
1611	Giovanni Demisiani (?–1614)	Introduced the term “telescope” for his optical device with three times (3X) magnification.
1611	Johannes Kepler (1571–1630)	Kepler presents the lens principles involved in the convergent, respectively, divergent properties applied to microscopes and telescopes in his publication <i>Dioptrice</i> . Based on this publication the “power” of a lens is expressed in diopters. In the same treatise, Johannes Kepler proposes the construction of a telescope using a converging objective and a converging ocular lens. This concept of the combination of lenses is still known as the telephoto lens. He also described the process and conditions of total internal reflection, but was unable to find a suitable mathematical relationship between the angle of incidence and the angle of refraction. Willebrord Snel (1591–1626) resolved this issue in 1621.
~1618	Christopher Scheiner (1573–1650)	Constructed a telescope of the type suggested by Johannes Kepler (1571–1630) with converging objective and eye lenses. This type of telescope has since become known as the “astronomical telescope”. So far no exact date for the construction of the first instrument of this design.
1621	Willebrord Snel (Snellius) van Royen (1591–1626)	Description of the relationship between the angle of incidence and angle of refraction at the interface when light passes from one transparent medium to another: Snell’s law.
1647	Bonaventura Francesco Cavalieri (1598–1647)	Derivation of the relationship between the radii of curvature for the respective two surfaces of a thin lens and the resulting focal length.
1657	Pierre de Fermat (1601–1665)	Introduction of the “mathematical” principle of “least time.” Based on this, a ray of light follows the path which takes the least amount of time to its destination. This shortest time path-length principle is consistent with Snell’s law of refraction.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1663	James Gregory (1638–1675)	Suggested the use of a converging mirror to be used as the objective of a telescope to mitigate for color aberrations, in his 1663 publication <i>Optica Promota</i> ; design of the “Gregorian reflecting telescope.” The Gregorian reflecting telescope was first built by Robert Hooke (1635–1703) in 1668.
1665	Francesco Maria Grimaldi (1618–1663)	Grimaldi’s observations of diffraction in the publication <i>Physico-Mathesis de lumine, coloribus et iride</i> (published posthumously). These were his observations regarding the passage of white light through small apertures. Grimaldi expressed his hypothesis that light is a fluid that exhibits wave-like motion.
1665	Robert Hooke (1635–1703)	Publication <i>Micrographia</i> , description of a compound microscope having both a converging objective lens and a converging ocular lens. In the same publication Hooke described his observations of the color displays produced in films of oil on water, flakes of mica, and in soap bubbles. He recognized that the color produced by light interaction with mica flakes is related to the thickness of the medium; however, he was unable to establish a specific relationship between thickness and obtained color. Hooke also advocated his own wave theory for the propagation of light.
1666	Sir Isaac Newton (1643–1727)	Description of the splitting up of white light into its spectral component colors when it passes through a prism.
1668	Robert Hooke (1635–1703)	Construction of the Gregorian reflecting telescope after the design by James Gregory (1638–1675) in 1663, using a reflecting converging mirror.
1668	Sir Isaac Newton (1643–1727)	Construction of the first reflecting telescope, in an attempt to compensate for chromatic aberration experienced by a refracting telescope.
1669	Rasmus Bartholinus (1625–1698)	Discovery of the double refraction in calcite.
1672	Sir Isaac Newton (1643–1727)	Documentation of the dispersion of sunlight passing through a prism. Newton concluded that the light emitted by the sun is composed of different colors, which are individually refracted by glass to different extents.
1676	Olaus (Ole) Christensen Rømer (Roemer) (1644–1710)	Deduced that the speed of light is finite based on his and his contemporary researchers’ detailed observations of the eclipses of Jupiter’s moons. From Rømer’s data, a value of about $2 \times 10^8 \text{ m.s}^{-1}$ can be obtained.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1678	Christiaan Huygens (1629–1695)	Publication <i>Traite de Lumiere</i> in 1690, to the Academie des Science in Paris, introduction of the Huygens wave theory of light. He considered that light is transmitted through an aether, made up of small elastic particles, each of which can act as a secondary wave source based on the wave mechanism Huygens was able to explain the majority of the known propagation characteristics of light, including discovery by Bartholinus regarding the double refraction in calcite.
1704	Sir Isaac Newton (1643–1727)	In his publication <i>Opticks</i> , Newton presented his corpuscular view for light, but that the corpuscles are able to perform waves in the aether. The corpuscular nature of light was based on the fact that light travels in straight lines whereas waves can refract (bend) into the shadow region of the object.
1727	James Bradley (1693–1762)	Bradley calculated the speed of light based on observations of the “aberration” of light from stars while attempting to detect stellar parallax, relying on the apparent motion of a star associated with the to be determined value of the speed of light in relation to the speed of the earth in its solar orbit. Explanation of the projection path aberration of light emitted by stars by forming the vector sum of the orbital velocity of the earth “ v ” next to the free space velocity of light “ c ”, and showed that the angle of aberration was a function of the ratio of these velocities: “ v/c ”. Based on this formulation Bradley showed that the revolution of the earth around the sun correctly accounted for the observed cyclic change in the optical aberration of star light rays. In comparison, the anti-Copernicans, which were still around in large numbers in the first half of the eighteenth century, were unable to refute this explanation of the change. Bradley’s work is the first of many instances that seemed to show (erroneously) that the value of the velocity of light depends on the motion of the observer.
1729/1733	Chester Moore Hall (1703–1771)	Construction of achromatic compound lenses using components consisting of glasses with different refractive indices. Construction of first refracting telescope that has chromatic aberration correction.
1752	Thomas Melvill (1726–1753)	Optical spectra imbedded in the light emission from flames, consisting of metals or salts; characteristic lines of representing the elements that define the constituents of the flame.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1801	Thomas Young (1773–1829)	Assisted in the development of the wave theory by demonstration of the interference properties of light.
1802	William Hyde Wollaston (1766–1828)	Discovery of the dark lines in the solar spectrum, but he was unable to interpret them in accordance with contemporary scientific knowledge.
1808	Étienne-Louis Malus (1775–1812)	Observed the light reflecting from the windows of the Palais Luxembourg in Paris through a calcite crystal as it was rotating, Malus uncovered an effect, which was later attributed to the polarization of light resulting from reflection.
1814	Joseph von Fraunhofer (1787–1826)	Rediscovery and description of the dark lines in the solar spectrum, originally noticed and documented by William Hyde Wollaston (1766–1828) in 1802 and determined the respective (not known at the time); “wavelength” locations with improved precision: Fraunhofer lines.
1815	Sir David Brewster (1781–1868)	Described the polarization direction for light resulting from reflection: Brewster angle.
1816	Augustin-Jean Fresnel (1788–1827)	Rigorous mathematical treatment of diffraction and interference phenomena illustrating that these phenomena can be explained based on a wave theory of light.
1816–1817	Augustin-Jean Fresnel (1788–1827) and Dominique François Jean Arago (1786–1853)	Interference of polarized light and the interpretation by Thomas Young (1773–1829), lead to the conclusion that light waves are transverse. Prior to this point in time the general assumption had been that electromagnetic radiation (light) has a longitudinal wave profile.
1819	Joseph von Fraunhofer (1787–1826)	Description of the diffraction of light by gratings. The gratings were initially made by winding rows of fine wires around screws lined up in parallel.
1821	Augustin-Jean Fresnel (1788–1827)	Presented the mathematical laws enabling the calculation of the radiant intensity (radiance) and direction of polarization for light reflected and refracted from an interface.
1823	Joseph von Fraunhofer (1787–1826)	Publication of the theory of diffraction.
1828	William Nicol (1770–1851)	Invention of the prism made from two calcite components, creating polarization of the transmitted light with respect to the two main axes: Nicol prism.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1834	John Scott Russell (1808–1882)	Observation of what is now referred to as a “solitary waves” and “wave of translation” based on his observations of a wave caused by a boat being drawn along the length of the Union Canal in Scotland. John Russell noticed how the wave travelled great distances without apparent change of shape. The study of solitary waves led to the solitons concept for optics, defining the light propagation in fiber-optics.
1835	George Biddell Airy (1801–1892)	Diffraction pattern produced by a circular aperture; associate resolution consequences: Airy disk.
1840	Carl Zeiss (1816–1888)	Lens fabrication initiated in Jena, Germany.
1845	Michael Faraday (1791–1867)	Rotation of the plane of polarization for light that is passed through glass exposed to a magnetic field: Faraday effect.
1847	Carl Zeiss (1816–1888)	Full-scale production of optical microscopes (Carl Zeiss AG, previously Carl Zeiss Jena).
1849	Armand Hypolite Louis Fizeau (1819–1896)	Speed of light measurement using a rotating toothed wheel to create an alternating pulsation of light beam. Fizeau made the first nonastronomical (nonvacuum) determination of the speed of light (in air), deriving a value of $313,300,000 \text{ m.s}^{-1}$. Note that the current accepted and verified speed of light in vacuum is $299,792,458 \text{ m.s}^{-1}$.
1849	Louis Pasteur (1822–1895)	Investigation of molecular asymmetry, joining his knowledge of crystallography, chemistry, and optics to obtain the optical polarization rotation. In specific, the reaction of tartaric acid derived by chemical synthesis under biological conditions or artificially. The reactions produce two mirror image molecules, with opposing effective rotated angle of polarization for the transmitted light: optical activity. The organic form of the product only has one rotation angle. Pasteur hence concluded that the molecule must be asymmetric and can have two forms, resembling left versus right hand.
1850	Jean Bernard Léon Foucault (1819–1868)	Foucault determined the speed of light in atmospheric air using a rotating mirror method, deriving a value of $298,000,000 \text{ m.s}^{-1}$. In the same year, Foucault used the same rotating mirror method to determine the speed of light in stationary water and found it to be less than in air. In 1851 Léon Foucault also positioned a pendulum with a string length of 67 meter in Paris, France, to illustrate the rotation of the earth, providing an arc rotation of the swing path in clockwise direction by 11 degree per hour; full circle in 37.2 hours.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1855	David Alter (1807–1881)	Description of the spectrum of hydrogen and other gases.
1859	Armand Hippolyte Louis Fizeau (1819–1896)	Experimental observation that the velocity of light in water is affected by flow of the water, the incremental change in the velocity of light being about a half of the velocity of the flowing water.
1860	Robert Wilhelm Eberhard Bunsen (1811–1899) and Gustav Robert Kirchhoff (1824–1887)	Recordings of the emission spectra of alkali metals in flames. Recognition of dark lines in the spectrum arising from absorption when illuminated by a bright light source through the flame. These dark lines are identical to the spectral lines observed in the solar spectrum observed by William Hyde Wollaston (1766–1828) and Joseph von Fraunhofer (1787–1826) in 1803: Fraunhofer lines, and it was argued that these lines in the sunlight are due to the absorption of light by gases in the solar atmosphere that are cooler than those “emitting the light” (not much was known about the mechanism-of-action of the sun, based on contemporary knowledge an oxidizing gas produces light).
1865	James Clerk Maxwell (1831–1879)	Combining his insights in the studies of the equations describing electric and magnetic fields, he derived that the speed of an electromagnetic wave should, within experimental error, be identical to the speed of light. Maxwell concluded from this that light is electromagnetic wave energy.
1869	John Tyndall (1820–1893)	Experimental studies of the light scattering pattern produced by aerosols.
1871	John William Strutt, third Baron Rayleigh (1842–1919)	Introduction of a general law relating the radiance of light scattered from small particles as a function of the wavelength, for particle dimensions smaller than the wavelength: Rayleigh scattering. This stand in contrast to Mie scattering (Gustav Mie [1869–1957]), where the scattering dimensions are larger than the wavelength. He also constructed a “zone plate” which resulted in focusing of light by Fresnel diffraction.
1873	Ernst Karl Abbe (1840–1905)	Detailed theory of image formation under observation by means of the microscope, specifically the resolution: Abbe criterion.
1874	Jacobus Henricus van't Hoff (1852–1911) and Joseph Achille Le Bel (1847–1930)	Each independently observed the optical activity (rotated polarization angle of the transmitted light) for carbon compounds. They both derived that this can be explained by a four (4)-way bound carbon atom (chemical saturation).
1875	John Kerr (1824–1907)	Quadratic electro-optic effect in glass: Kerr effect.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1879	Josef Stefan (1825–1893)	Publication of an empirical relationship defining the total radiant energy emitted from the surface of a body per unit time to be proportional to the fourth power of the absolute temperature of that body.
	Sir Joseph Wilson Swan (1828–1914)	Demonstration of an incandescent light bulb with a carbon filament.
1879	Thomas Alvin Edison (1847–1931)	Development and sale of a working electric lamp using cotton as a carbon filament.
1882	Albert Abraham Michelson (1852–1931)	Michelson interferometer.
1885	Johann Jakob Balmer (1825–1898)	Definition of an empirical formula describing the wavelength position of the emission lines in the visible part of the hydrogen. Spectrum: Balmer series.
1887	Albert Abraham Michelson (1852–1931) and Edward William Morley (1838–1923)	Failure to verify the illusive concept of “luminiferous aether” (in fact, electromagnetic radiation does not require an “aether”) by correlation of speed of light to the direction in which the light beam moves: the Michelson–Morley experiment.
1887	Heinrich Rudolf Hertz (1857–1894)	Discovery of the photoelectric effect, primarily by accident. Heinrich Hertz experimentally proved the electromagnetic wave concept, theoretically described by James Clerk Maxwell (1831–1879). Heinrich Hertz is a nephew of the Gustav Ludwig Hertz (1887–1975).
1890	Otto Heinrich Wiener (1862–1927)	Recognition of standing waves produced by light reflecting at normal incidence from a silver mirror. Nodes and antinodes in the standing electromagnetic wave were recorded photographically illustrating a node at the mirror surface, yielding the electric field to be zero (no electric field inside a conductor). From this it was derived that the electric component of the electromagnetic wave carries the more important effect, at least for this time of detection.
1891–1892	Ludwig Mach (1868–1951) and Ludwig Louis Albert Zehnder (1854–1949)	Description of the respective interferometer efforts of Ludwig Mach in 1892 and Ludwig Zehnder in 1891 independently, what has become known as the Mach–Zehnder interferometer with the ability to monitor changes in refractive index, and inherent density, with respect to compressible gas flows. The Mach–Zehnder interferometer has found apropos applications in the field of aerodynamics. The optical path for the interferometer is governed by the Fermat principle (Pierre de Fermat [1601–1665]). Ludwig Mach is the son of Ernst Waldfried Josef Wenzel Mach (1838–1916).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1896	Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928)	Description of the spectral distribution (peak emission wavelength) of radiation from a black body as a function of the temperature of the body.
1896	Pieter Zeeman (1865–1943)	Observation of the broadening of the spectral lines emitted by an atomic source when the source is exposed to an external magnetic field.
1899	John William Strutt, the 3rd Baron Rayleigh (1842–1919)	Explanation of the principles for the blue color of the sky as well as the red sunsets resulting from preferential scattering angle as a function of wavelength for white light by molecules in the earth's atmosphere.
1899	Marie Paul Auguste Charles Fabry (1867–1945) and Charles Fabry and Alfred Pérot (1863–1925)	Description of the Fabry–Perot interferometer, enabling high-resolution observation of spectral features.
1900	Max Karl Ernst Ludwig Planck (1858–1947)	Successful explanation of the spectrum of radiation emitted from a heated black body. Planck introduced a universal constant in his proportionality equation as the “quantum of action,” now known as Planck's constant. As a consequence the energy of an oscillator is the sum of small discrete units, each of which has a value that is proportional to the respective oscillation frequency.
1902	Woldemar Voigt (1850–1919)	Discovery of magnetic birefringence, or magnetic double refraction. The Voigt effect has several similarities to the Faraday effect.
1905	Albert Einstein (1879–1955)	Explanation of the photoelectric effect based on the assumption that light is quantized, these electromagnetic energy quanta become known as photons.
1908	Gustav Mie (1869–1957)	Presented a description of light scattering from particles that are not small compared to the wavelength of light, taking account of particle shape and the difference in refractive index between the particles and the supporting medium. This stands in contrast to Rayleigh scattering (John William Strutt, the 3rd Baron Rayleigh [1842–1919]), where the scattering dimensions are smaller than the wavelength.
1908	Walter Ritz (1878–1909)	Announcement of the combination principle for computing the frequencies of spectral lines.
1908	Louis Carl Heinrich Friedrich Paschen (1865–1947)	Experimental verification of the existence of a spectral series of hydrogen in the near infrared predicted by the Rydberg–Ritz relation.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1910–1912	Victor Franz Hess (1883–1964) and Werner Kol Hoerster (1887–1945)	Discovery of cosmic rays. Victor Franz Hess was awarded the Nobel Prize in Physics jointly with Carl David Anderson (1905–1991) in 1936.
1913	Neils Henrik David Bohr (1885–1962)	Atom model in which the electrons were presumed to occupy stable orbits demarcated by well-defined energy levels. This theory underwrites the quantum aspect of the absorption and emission of light by an atom resulting from the acceleration of an electron moving from one orbit to another orbit of different energy. This also provides an explanation of the absorption and emission at particular frequencies that are characteristic for that particular atomic energy configuration, depending on the element in question.
1915	William David Coolidge (1873–1975)	Patent on a method for creating tungsten electric lamp filaments.
1916	Albert Einstein (1879–1955)	Proposed stimulated emission of light process, complementing the standard absorption and spontaneous emission.
1919	Sir Arthur Stanley Eddington (1882–1944)	Observation of the solar eclipse on May 29 at Príncipe Island off the west coast of Africa. it was Eddington's intention to determining the apparent position of stars that are visible close to the sun's disk. From this he managed to conclude that the path of light from these stars is bent by the sun's gravitational field, conforming to the predictions of the theory of general relativity by Albert Einstein (1879–1955).
1926	Albert Abraham Michelson (1852–1931)	Determination of the speed of light by means of a rotating mirror with a light path from the observatory at Mount Wilson, Pasadena, California, spanning a distance of 35 km to a reflector on Mount San Antonio. Average value $c = 299,796,000 \text{ m.s}^{-1}$.
1927	Paul Adrien Maurice Dirac (1902–1984)	Presentation of electromagnetic radiation field in quantized form.
1928	Sir Chandrashekhara Venkata Râman (1888–1970)	Inelastic scattering of light from liquids, weak radiance line shifts. The effect arises from the scattering of light by vibrating molecules and is known as Raman scattering.
1932	Roy James Kennedy (1897–1973) and Edward Moulton Thorndike (1905–)	Experimentally attempted to detect the aether drift with a very stable and refined form of interferometer having arms of unequal length. Both the length and the time transformations of the special theory of relativity had to be used to account for the null result.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1932	Peter Joseph William Debye (1884–1966) with Francis Weston Sears (1898–1975) next to René Lucas (1898–1990) and Pierre Biquard (1901–1992)	Description of diffraction of electromagnetic radiation by ultrasonic waves; beginning of acousto-optics.
1932	Edwin Herbert Land (1909–1991)	Invention of the “polaroid” polarizing film.
1934	Frits Zernicke (1888–1966)	Description of the phase-contrast microscope.
1939	Walter H. Geffcken (1904–1995)	Description of the transmission interference filter.
1941	W. Canton Anderson ()	Measured the speed of light using a Kerr cell used to modulate a light beam passing through a Michelson interferometer. Obtained the value $c = 299,776,000 \text{ m.s}^{-1}$. Note that the current accepted and verified speed of light in vacuum is $299\,792\,458 \text{ m.s}^{-1}$.
1947	Willis Eugene Lamb, Jr. (1913–2008) and Robert E. Retherford (1882–1939)	During the course of spectral measurements of the fine structure of hydrogen in the microwave region of electromagnetic radiation, made the observation of a small displacement (the “Lamb shift”) of an energy level from its theoretical position as predicted by Dirac’s quantum theory of the electron (Paul Adrien Maurice Dirac [1902–1984]). Lamb was awarded the Nobel Prize in Physics jointly with Polykarp Kusch (1911–1993) in 1955.
1948	Dennis Gabor (1900–1979)	Description of the principles of wave front reconstruction, evolving into holography.
1954	Charles Hard Townes (1915–2015), James Power Gordon (1928–2013) and Herbert J. Zieger (1925–2011)	Publication: “Molecular microwave oscillator and new hyperfine structures in the microwave spectrum of NH_3 ,” describing the maser at Columbia University operating on ammonia producing coherent microwave radiation: MASER. Charles Hard received the Nobel Prize in Physics in 1964.
1958	Arthur Leonard Schawlow (1921–1999) and Charles Hard Townes (1915–2015)	Publication of “Infrared and Optical Masers” in which the maser principle were proposed to be extended into the visible region of the electromagnetic spectrum, creating the “laser” concept.
1958	Gordon Gould (1920–2005)	Arguably one of the first people to design, build, and operate a laser.
1960	Theodore Harold Maiman (1927–2007)	Described the first operational laser, built at the Hughes Research Laboratories, operating a rod of synthetic ruby as the medium: Ruby LASER.
1960	Ali Javan [Persian: جوان علی] (1926–)	Construction and operation of the first helium-neon laser.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1961	Peter Alden Franken (1928–1999), Arthur E. Hill (–2014), C. W. Peters () and Gabriel Weinreich (1930?–)	Demonstrated harmonic generation, specifically second harmonic, from laser light by transmission of the ruby laser pulse through a quartz crystal.
1961	Ali Javan (1926–), William Ralph Bennett (1930–2008), and Donald R. Harriott (1928–2007)	First gas laser at the Bell Laboratories. Lasing medium was a helium and neon mixture, emitting in the near infrared, the line with highest radiance at a wavelength of 1153 nm.
1962	Marshall I. Nathan, Robert H. Rediker, Robert N. Hall, W. Keyes, Ted M. Quist, Nick Holonyak (1928–) and S. F. Bevacqua	Five groups describing the observation of stimulated emission from gallium arsenide semiconductor diodes: inception of the diode laser. Based on the pioneering work of Captain Henry Joseph Round (1881–1966) in 1907 and Rubin Braunstein () in 1955.
1963	Chandra Kumar Naranbhai Patel (1938–)	The first carbon dioxide laser, Bell Laboratories.
1964	William B. Bridges (1934–)	First ion laser built at Hughes Research Laboratories.
1964	Jerome V. V. Kasper () and George Claude Pimentel (1922–1989)	Photodissociation mechanism of action description for the Iodine laser. The laser operated at a wavelength of 1315 nm at the University of California, Berkeley. The population inversion in atomic iodine was induced by the photodissociation of either CH_3I or CF_3I .
1966	Peter P. Sorokin (1931–) and John R. Lankard ()	First organic dye laser
1967–1969	S. L. McCall () and E. L. Hahn ()	Described studies of the propagation of very short optical pulses through a medium consisting of resonant two level atoms, developing in the process the criteria to be satisfied by the shape of the pulse so that it would propagate as an optical soliton (the area theorem) and describing the propagation mechanism of self-induced transparency (SIT).
1971	John M. J. Madey (1943–)	Publication: “Stimulated emission of bremsstrahlung in a periodic magnetic field,” Madey describes the principles of the free electron laser.
1976	John M. J. Madey (1943–)	Stanford University group operates the first free electron laser (FEL).
1985	Dennis L. Matthews ()	X-ray laser at the Lawrence Livermore National Laboratory, operating at 20 nm emission wavelength band.
1990		The Hubble space telescope is positioned in a low orbit around Earth on April 25, 1990.

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Quantum

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1850	Sir William Rowan Hamilton (1805–1865)	Reformulation of Newtonian mechanics: Hamilton mechanics. Hamilton mechanics can be considered an essential building block to the development of quantum mechanics. Sir William Hamilton introduced the principles leading to the formulation of the Hamiltonian operator used in quantum mechanics, defining the total energy of a system.
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure and quantum theory.
1922	Erwin Rudolf Josef Alexander Schrödinger (1887–1961) and Hermann Klaus Hugo Weyl (1885–1955)	Introduction of the quantum mechanical principles, which formed the basis for several imaging techniques.
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all object in motion. Matter wave, propagating with the de Broglie wavelength.
1927	Wolfgang Ernst Pauli (1900–1958) Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles. This formed the foundation for the development of the NMR imaging system: nuclear magnetic resonance (MRI).
1937	John Archibald Wheeler (1911–2008)	Theoretical physics and relativity. Corrections to the Bohr (Niels Bohr [1885–1962]) liquid drop model.
1948	Richard Phillips Feynman (1918–1988)	Introduction of the Feynman diagrams.
1957	Rudolf Ludwig Mössbauer (1929–2011)	Discovery of atomic recoilless nuclear energy interaction under gamma radiation resulting in resonance fluorescence: Mössbauer effect.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Никола́й Генна́диевич Ба́сов] (1922–2001), and Aleksandr Mikhailovich Prokhorov [Алекса́ндр Миха́йлович Про́хоров] (1916–2002)	Quantum electronics.

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Solid-state

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
"Ancient man"		Realization that the following chemical compounds were pure; what we currently consider as elements: gold (8000 BC), silver (<5000 BC), iron (<5000 BC), copper (9000 BC), mercury (<2000 BC), tin (~3500 BC), carbon (3750 BC), and sulfur (2000 BC).
450 BC	Leucippus (fifth century BC)	Argued that the universe consists as a structure of atoms and voids.
430 BC	Democritus (of Greece) (460 BC–370 BC)	Proclamation that the atom is the smallest and simplest unit of all matter. All matter is composed of atoms. The first rudimentary introduction of the elementary build block but with no scientific support. Greek word "atomos" (ἄτομος), meaning indivisible.
350 BC	Aristotle (384 BC–322 BC)	Declaration of only four (4) elements defining the existence on earth: fire, water, air, and earth. Matter only has the following properties: wet, dry, hot, or cold.
300	Alchemists:	Based on the philosophy of Aristotle the alchemists believed that "regular" metals could be converted into precious metal, specifically gold; wishful thinking... The item required to perform this conversion was referred to as the elusive "philosopher's stone."
1615	Jean Beguin (1550–1620)	First diagram expression for a chemical reaction in a notation that we still adhere to today.
1661	Robert Boyle (1627–1691)	First "modern chemist." End of the era of the Alchemists (perpetuated for 2000 years), partially based on the book by Robert Boyle <i>The Sceptical Chymist</i> .
1669	Henning Brand (1630–1710)	Documented observation that phosphorus is an element.
ca. 1670	Sir Isaac Newton (1643–1727)	Sir Isaac Newton was one of the prominent proponents and advocates of the atom theory.
1757	William Cullen (1710–1790)	Introduction of the first formula for a chemical reaction.
1774	Antoine Lavoisier (1743–1794)	Discovery of oxygen; and the chemical process of oxidation.
1785	Charles Augustin de Coulomb (1736–1806)	Treatise on electricity: <i>Premier Mémoire sur l'Électricité et le Magnétisme</i> . The unit of electric charge is named after him posthumously. The free electric charge is the electron, which was neither fully understood, nor described. The electron does form the basis for strong chemical connections, based on ion formation.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1789	William Higgins (1763–1825)	First use of the term molecule describing a chemical compound consisting of multiple atoms. The word molecule can be traced back to 1678. The expression and concept of the molecule has ties to Rene Descartes (1596–1650) and Robert Boyle (1627–1991).
ca. 1800	John Dalton (1766–1844)	Introduction of the “law of multiple proportions” describing the atomic concept based on chemical reactions taking place in ratios of small whole numbers.
1806	Sir Humphry Davy, 1st Baronet (1778–1829)	Discovery of several alkali next to alkaline earth metals, as well as contributions to the description and discovery of the elemental nature of the elements chlorine and iodine.
1804	Christian Samuel Weiss (1780–1856)	Description of crystalline structure as a configuration of attractions and repulsions, based on the work of René Just Haüy (1743–1822).
1807	Thomas Young (1773–1829)	Formal introduction of the Young’s modulus for elastic deformation, tying strain to stress, based on the work by Leonard Euler (1707–1783).
1820	Pierre Louis Dulong (1785–1838) and Alexis-Thérèse Petit (1791–1820)	Dulong and Petit law of specific heats; coupled oscillators.
1820	Claude Louis Marie Henri Navier (1785–1836)	Efforts on developing mathematical models describing molecular concepts for elasticity of three-dimensional isotropic bodies, expressed in <i>Lois de l’équilibre et du mouvement des corps solides</i> .
1826	Franz Ernst Neumann (1798–1895)	Mathematical description of the “crystalline structure.” Franz Neumann additionally described the heat exchange and specific heat concept based on the work of Alexis-Thérèse Petit and Pierre Louis Dulong (Dulong–Petit law). This was published almost 30 years later as the Kopp–Neumann rule, by his student Hermann Franz Moritz Kopp (1817–1892). Student of Christian Samuel Weiss (1780–1856).
1827	Augustin-Louis Cauchy (1789–1857)	Theory of linear elasticity: Cauchy relations.
1850	Sir William Rowan Hamilton (1805–1865)	Sir Hamilton is most known for his reformulation of Newtonian mechanics: Hamilton mechanics. Hamilton mechanics can be considered an essential building block to the development of quantum mechanics. Sir William Hamilton introduced the principles leading to the formulation of the Hamiltonian operator used in quantum mechanics, defining the total energy of a system.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1850	Auguste Bravais (1811–1863)	Uncovered lattice structure: Bravais lattice.
1850	George Boole (1815–1864)	Known for the Boolean algebra and logic. The work of George Boole inspired Claude Shannon (1916–2001).
1852	Wilhelm Eduard Weber (1804–1891)	Molecular model for magnetism, based on the “molecular rotation,” which allows alignment of the electrical eddy currents to form a magnetic solid with a defined North and South pole under application of an external magnetic field. Assisted by the work of Sir James Alfred Ewing (1855–1935).
1853	Gustav Heinrich Wiedemann (1826–1899) and Rudolf Franz (1827–1902)	Relationship between electrical conductivity and thermal conductivity for a solid medium.
1857	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Introduction of chemical thermodynamics concepts and definitions and electrodynamics.
1860	Georg Friedrich Bernhard Riemann (1826–1866)	The work of Bernhard Riemann was instrumental in the development of the development of the theory of general relativity and the supporting mathematical evaluation.
1864	Augustus Matthiessen (1831–1870)	Description of the specific conductivity of materials as a function of temperature and impurities in the solid medium.
1865	James Clerk Maxwell (1831–1879)	Electromagnetic theory.
1870	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Unofficial introduction to the mechanism of action for nuclear fusion.
1873	Josiah Willard Gibbs (1839–1903)	Chemical potential, a energy constituent within the Gibbs free energy. Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction.
1879	William Crookes (1832–1919)	Cathode rays and realization that single charged particles must be involved.
1879	Edwin Hall (1855–1938)	Description of the “Hall effect”: the expression of a transverse force on the electric charges within a conductor carrying a current while exposed to an external magnetic field: polarization resulting in a measurable electric potential between the lateral sides of the conductor.
1880	Pierre Curie (1859–1906) and Jacques Curie (1856–1941)	Discovery of the generation of electricity by mechanical manipulation of crystals: piezoelectric concept.
1884	Ludwig Minnigerode (1773–1839)	Recognition of at least 32 possible crystal classes, based on his mentor’s work: Franz Ernst Neumann (1798–1895).

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1885	Eugene Goldstein (1850–1930)	Principle discovery of the proton, however not recognized as such.
1888	Heinrich Friedrich Weber (1843–1912)	Discovery that the emitted wavelength band from a heated body changed the peak wavelength location as a function of the measured temperature. This paved the way for the radiation formula released by Max Planck (1858–1947), it also provided the entry into quantum theory.
1890	Jules Henri Poincaré (1854–1912)	Introduction of methods and means for deriving accurate topographical data. Some of the work of Poincaré revolved around defining the geometry of the universe. Poincaré also contributed to fluid dynamic modeling in addition to the description of celestial motion.
1896	Wilhelm Conrad Röntgen (1845–1923)	Discovery of X-ray radiation.
1896	Henri Becquerel (1852–1908)	Emission of “Becquerel rays” from uranium salts, later identified as alpha particles. Becquerel already recognized that this emission was different from X-ray since it was deflected by means of an applied external magnetic field. Conceptual introduction to the field of radioactivity.
1897	Joseph John Thomson (1856–1940)	Discovery of the electron concept; using William Crookes’s vacuum tube. The electron itself was at this point not identified.
1897	Joseph John Thomson (1856 – 1940)	Introduction of the concept “ionic bond,” also referred to as polar bond.
1897	Marie Skłodowska-Curie (1867–1934)	Discovery of radioactive isotopes. Marie Curie introduced the term “radioactivity.”
1899	Paul Karl Ludwig Drude (1863–1906)	Introduction of the “free electron gas” for conduction in metals, based on his work under Woldemar Voigt (1850–1919). Additional work by Paul Drude was in optics, specifically the description of light and interaction with (transparent) object base on the theories of James Clerk Maxwell (1831–1879).
1899	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Emission of alpha particle.
1900	Samuel Giuseppe Vito Volterra (1860–1946)	Description and formulation of cylindrical waves. Volterra became involved in the biological cause and effect, respectively predator–prey, aspects, pioneering the field of mathematical biology.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1900	David Hilbert (1862–1943)	Hilbert space: vector space designed to accommodate an infinite number of dimensions, with respect to the three-dimensional Euclidean space. The Hilbert spatial interpretation forms an indispensable tool in solving for partial differential equations, as well as pertaining to quantum mechanics, and Fourier analysis. In Fourier analysis this applies to applications in signal processing and heat transfer. Hilbert Space is an ergodic theory, which provides the mathematical foundations of certain thermodynamics topics.
1900	Max Karl Ernst Ludwig Planck (1858–1947) and James Clerk Maxwell (1831–1879)	Formal description of the photon and the energy associated with the electromagnetic wave. Introduction of Planck's radiation law.
1903	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Discovery of the nuclear decay half-life.
1903	Marie Skłodowska-Curie (1867–1934) and Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Quantification of nuclear decay.
1905	Albert Einstein (1879–1955)	Energy–mass equivalence hypothesis introduced. Einstein also published his theoretical interpretation of the movements of object, specifically approaching the speed of light in his special theory of relativity and general theory of relativity. In 1917 he published his predictions on stimulated emission and hence the preliminary description of the operations of a LASER. Additional mathematical work eludes to quantum theoretical approach.
1906	Dmitri Ivanovich Mendeleev (1834–1907)	Periodic Table of Elements.
1907	Pierre-Ernest Weiss (1865–1940) and Paul Langevin (1872–1946)	Refinement of the local magnetic field in ferromagnetic materials, the early work by Wilhelm Eduard Weber (1804–1891).
1908	Johannes Geiger (1822–1945) and Ernest Rutherford (1871–1937)	Development of the Geiger counter, used to measure radioactive radiation.
1909	Francis Aston (1877–1945)	Mass spectrometer mass separation of closely separated isotopes. Highly sensitive mass spectrometer design.
1909	Robert Andrews Millikan (1868–1953)	Measurement of the mass of the electron.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1910	Amalie Emma Noether (1882–1935)	Master of abstract algebra. Amalie Noether also introduced the concept of conservation laws based on the symmetry in nature and physics and engineering.
1910	Hermann Klaus Hugo (Peter) Weyl (1885–1955)	Weyl studied under David Hilbert (1862–1943) and was also close to Amalie Emma Noether (1882–1935). Hermann Weyl uncovered a gauge invariance and with his interpretation of Riemann surfaces his teachings form the basis of many aspects supporting the theoretical explanation in modern physics concepts. Weyl also contributed to the efforts of Erwin Schrödinger (1887–1961).
1911	Heike Kamerlingh Onnes (1853–1926)	Discovery of superconductivity. Building on the resistance measurements at low temperatures by Sir James Dewar (1842–1923) and J. Andrew Fleming (1846?–1928?) in 1892.
1911	Ernest Rutherford (1871–1937), 1st Baron Rutherford of Nelson, Lord Rutherford of Nelson	Rutherford scattering on nuclear level, indication of the existence of the proton. The proton itself was not mentioned until 1932, this time again by Ernest Rutherford.
1911	Niels Henrik David Bohr (1885–1962)	Elaboration on the “electron gas model” introduced by Paul Karl Ludwig Drude (1863–1906) in 1899.
1912	Max Theodor Felix von Laue (1879–1960)	Established wave nature of X-rays represented by an interference pattern by means of crystal diffraction. Max von Laue received the Nobel Prize in Physics for his discovery in 1914.
1912	Max Born (1882–1970)	Description of the vibration mechanics in (crystalline) lattice structures, providing a fundamental theoretical formulation of the specific heat concept introduced by Albert Einstein (1879–1955) in 1911.
1913	Niels Henrik David Bohr (1885–1962)	Bohr atomic model.
1913	Frederick Soddy (1877–1956)	Formal introduction of the isotope concept.
1913	William Lawrence Bragg (1890–1971) and William Henry Bragg (1862–1942)	Bragg X-ray diffraction for crystal lattice structure: Bragg law. This may often be considered the official beginning of the field for condensed matter physics, respectively, solid-state physics.
1913	Gilbert Newton Lewis (1875–1946)	Introduction of the free electron metallic bond; based on the work by Paul Karl Ludwig Drude (1863–1906).
1914	Niels Henrik David Bohr (1885–1962)	Description of the atomic energy layer model; hydrogen (Bohr atomic model).
1915	Ernest Marsden (1889–1970)	Artificial transmutation, associated with radon enclosed by vacuum.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1916	Niels Henrik David Bohr (1885–1962)	Atomic structure and quantum theory.
1916	Gilbert Newton Lewis (1875–1946)	Description of the shell filling for atomic electrons, and the related covalent bond and the concept of valence electrons.
1917	Ernest Rutherford, 1st Baron Rutherford of Nelson (1871–1937)	Discovery of the proton.
1918	Paul Scherrer (1890–1969)	X-ray diffraction, crystal structure. Nuclear energy development. Established the CERN institute in Switzerland as one of the founders. Directed the construction of the first cyclotron in 1940.
1919	Ernest Rutherford (1871–1937)	Artificial transmutation, hydrogen formation resulting from collisions of alpha particles with nitrogen, also generating oxygen and gamma rays.
1921	Willem Hendrik Keesom (1876–1956)	Keesom theory for degenerate gas. Description of dipole–dipole interaction. William Keesom provided a description of the specific heat at low temperatures. Keesom also managed to freeze helium in 1926.
1921	Alfred Landé (1888–1976)	Mathematician who introduced the Landau factor for an electron with both self-rotation spin and orbital angular momentum.
1922	Erwin Rudolf Josef Alexander Schrödinger (1887–1961) and Hermann Klaus Hugo Weyl (1885–1955)	Introduction of the quantum mechanical principles, supporting the understanding of high-energy physics phenomena such as the atomic structure.
1923	John von Neumann (1903–1957) [original name: Neumann Janos Lajos]	Introduced finite element methodology (also known as Monte Carlo simulation), integration of random number generation. He was also instrumental in the design of thermonuclear bombs as well as significantly advanced the field of hydrodynamics.
1923	Arthur Holly Compton (1892–1962)	Description of the deflection of photons by a charge unit, generally an electron, potentially the nucleus: Compton effect.
1924	Niels Henrik David Bohr (1885–1962)	Introduction of the term: “element”. This idea was formed based on Wolfgang Pauli’s (1900–1958) exclusion principle. The element concept has been around for millennia.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1924	Satyendra Nath Bose (1894–1974) [সত্যেন্দ্র নাথ বসু] and Albert Einstein (1879–1955)	Introduction of the Bose–Einstein statistics: one of two potential manners of energy occupation for a collection of noninteracting indistinguishable particles with respect to a set of available discrete energy states, this applies to thermodynamic equilibrium only. At extreme low temperatures these energy levels for bosons can result in a joining of states: condensation, the Bose–Einstein condensate.
1924	Sir John Edward Lennard-Jones (1894–1954)	Definition of the attraction between two neutral molecules or atoms: Lennard Jones potential.
1924	Louis-Victor-Pierre-Raymond, 7th duc de Broglie (1892–1987)	Introduction of the wave phenomenon with respect to all object in motion. Matter wave, propagating with the de Broglie wavelength.
1925	Werner Heisenberg (1901–1976)	Introduction of quantum mechanics, specifically in matrix formulation. Heisenberg also introduced the “uncertainty principle”; two parameters describing the same item or phenomenon cannot be known simultaneously with exact accuracy, such as momentum and position, but are inherently linked to each other with a product that yields the reduced-Planck-constant divided by two or greater.
1925	Wolfgang Ernst Pauli (1900–1958)	Pauli exclusion principle for atomic energy levels.
~1925		Recognition of the “Coulomb barrier” in nuclear collision, providing a “tunneling” effect for the release of alpha particles.
~1926	Paul Langevin (1872–1946)	Elaborate work on paramagnetism and diamagnetism with a significant contribution to the development of ultrasound detection based on the piezoelectrics effect discovery by Pierre Curie (1859–1906) and Jacques Curie (1856–1941) in 1888. Paul Langevin introduced the “Twin Paradox” concept with respect to Special Relativity introduced by Albert Einstein (1879–1955).
1926	Paul Dirac (1902–1984) and Enrico Fermi (1901–1954)	Fermi–Dirac statistics.
1926	1928: Paul Dirac (1902–1984); 1929 Dmitri Vladimirovich Skobeltsyn (1892–1990); 1932 Carl David Anderson (1905–1991)	Discovery of positron.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1926	Eugene Paul Wigner (1902–1995)	Series publications on the application of group theory in quantum mechanics. Eugene Wigner shared the Nobel Prize in Physics jointly with Maria Goeppert-Mayer (Göppert) and Johannes Hans Daniel Jensen (1907–1973) in 1963.
1926	Jean Baptiste Perrin (1870–1942)	Physical proof providing the existence of molecules.
1927	Werner Karl Heisenberg (1901–1976)	Quantum Uncertainty Principle.
1927	Paul Adrien Maurice Dirac (1902–1984)	Description of antimatter.
1927	Wolfgang Ernst Pauli (1900–1958) Ralph Kronig (1904–1995), George Eugene Uhlenbeck (1900–1988), Samuel Abraham Goudsmit (1902–1978), and Paul Adrien Maurice Dirac (1902–1984)	Introduction of the electron spin concept and a broad range of relativistic quantum mechanical principles. This formed the foundation for the development of the NMR imaging system: nuclear magnetic resonance (MRI).
1928	Arnold Johannes Wilhelm Sommerfeld (1868–1951)	Theory of metals: free electron model that obeys the Fermi–Dirac statistics; Paul Adrien Maurice Dirac (1902–1984) and Enrico Fermi (1901–1954).
1928	Johannes Geiger (1822–1945) and Walther Müller (1905–1979)	Introduction of an improved Geiger counter: the Geiger–Müller counter, using ionization of a confined gas.
1928	Sir Chandrasekhara Ventaka Raman (1888–1970)	Raman spectroscopy; indicating the energy levels in atoms and molecules.
1928	Felix Bloch (1905–1983)	Description of the migration process of electrons in an atomic lattice structure. The electron transport formed what Felix Bloch referred to as a wave process, now referenced as Bloch waves. The wave process (i.e., wavelength) directly corresponds to the periodic nature of the lattice structure, in particular for a crystal.
1930	Enrico Fermi (1901–1954)	Chemical potential for electrons: Fermi level, equivalent to the thermodynamic work required to add or remove an electron to the energy configuration of the body. This applies in particular to semiconductors and the working of p-type[and n-type-doped materials such as diodes and transistors.
1931	Linus Carl Pauling (1901–1994)	Description of the general and detailed nature of various types of chemical bonds.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1931	Wolfgang Ernst Pauli (1900–1958)	Theoretical introduction of the neutrino. The experimental verification of the existence of the neutrino was not until 1956 by Frederick Reines (1918–1998) and Clyde Cowan Jr. (1919–1974).
1931	Carl David Anderson (1905–1991)	Discovery of the positron, antiparticle for the electron. The “positron” was predicted by Paul Adrien Maurice Dirac (1902–1984) in 1929.
1932	Sir James Chadwick (1891–1974)	Discovery of the neutron. Student of Ernest Rutherford (1871–1937).
1934	Leo Szilard (1898–1964)	Recognition of nuclear decay chain reactions.
1934	Hideki Yukawa [湯川 秀樹], (1907–1981)	Introduction of mesons and the concept of antimatter.
1934	Ida Noddack (1896–1978)	Formal introduction of the concept of “fission,” however, not recognized by her peers at the time. The fission phenomenon was only recognized when announced by Enrico Fermi (1901–1954) later that year.
1934	Enrico Fermi (1901–1954)	Interaction of slow neutron with nuclei and the resulting decay into different elements, including aluminum and uranium.
1935	Enrico Fermi (1901–1954)	Developed Fermi–Dirac statistics, although independent from Paul Dirac (1902–1984) but simultaneously. The Fermi–Dirac statistics applies to fermions, while the counterpart that it does not include are referred to as bosons. Fermi worked on X-ray crystallography, as well as energy levels in semiconductor structures. The Fermi level concept for electrons in atomic energy approximating absolute zero ties directly in with the Pauli exclusion principle. Fermi worked with and studied under Max Born (1882–1970), Werner Heisenberg (1901–1976), Pascual Jordan (1902–1980), Paul Ehrenfest (1880–1933), Hendrik Lorentz (1853–1928), Samuel Goudsmit (1902–1978), Jan Tinbergen (1903–1994), and Albert Einstein (1879–1955). Fermi concluded that beta decay from the nucleus formed another energetic particle and determined it to be real and named it a neutrino.
1935	Paul Adrien Maurice Dirac (1902–1984)	Developed Fermi–Dirac statistics, although independent from Enrico Fermi (1901–1954) but simultaneously.
1935	Arthur Dempster (1886–1950)	Discovery of the lighter uranium isotope: Uranium-235.
1936	Otto Hahn (1879–1968) and Lise Meitner (1878–1968)	Neutron collision of uranium-induced decay examination.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1937	Carl David Anderson (1905–1991), Seth Henry Neddermeyer (1907–1988), Jabez Curry Street (1906–1989), and Edward C. Stevenson ()	Confirmation of the existence of the meson, and muon.
1938	Niels Henrik David Bohr (1885–1962) and John Archibald Wheeler (1911–2008)	Formal description of the nuclear fission process.
1939	Jerome M. B. Kellogg (1905–)	Discovery of a finite quadruple moment for the deuteron, requiring a noncentral (tensor) nuclear force configuration.
1940	Otto Robert Frisch (1904–1979)	Development of the detonation mechanism for the first atomic bomb
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more.
1947	Charles Kittel (1916–)	Elaborate theoretical work on solid-state physics, respectively: condensed matter physics.
1947	George Dixon Rochester (1908–2001), Clifford Charles Butler (1922–1999)	Discovery of the subatomic particle: the “kaon,” k-meson. Introduction of the “strangeness” concept for quarks, although the quark concept had not been introduced. In the elementary particle phenomenology the kaon is a bound state of an up- or down quark with a strange quark (antiquark).
1947	Maria Goeppert-Mayer (Göppert) (1906–1972)	Theoretical concept development for the understanding of nuclear forces, based on a shell model, similar to the atomic electron model.
1947	William Webster Hansen (1909–1949)	Linear accelerator installation at Stanford University, California.
1950	Maria Goeppert-Mayer (Göppert) (1906–1972)	Introduction of the nuclear shell model of atomic nuclei.
ca. 1952	Ludwig von Helmholtz (1821–1894), Lyman Strong Spitzer, Jr. (1914–1997), and Ronald Richter (1909–1991) and Edward Teller (1908–2003)	Nuclear fusion investigation and start of experimentation. The process was in principle described by Hermann Ludwig Ferdinand von Helmholtz (1821–1894), but is continuously in action at the sun’s surface.
1955	Obninsk Nuclear Power Station, Russia	First nuclear power station for energy generation.
1956	Frederick Reines (1918–1998) and Clyde Lorrain Cowan Jr. (1919–1974)	Experimental confirmation of the neutrino introduced in 1931 by Wolfgang Pauli (1900–1958).

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1957	John Bardeen (1908–1991), John Robert Schrieffer (1931–) and Leon N. Cooper (1930–)	Bardeen–Cooper–Schrieffer theory of superconductivity.
1958	Stanley Mandelstam (1928–)	Introduction of Mandelstam variables associated with the concept of “crossing symmetry,” defining numerical quantities which encode the energy, momentum, and scattering angles of particles in a deflection process described in a Lorentz-invariant fashion.
1958	Lev Davidovich Landau [Russian: Лёв Давидович Ландау] (1908–1968), Arkady Beynusovich Migdal [Russian: Аркадий Бейнусович (Бенедиктович) Мигдал] (1911–1991)	Theory of interacting electrons, specifically with respect to solids; condensed matter physics.
1961	Murray Gell-Mann (1929–)	Description of elementary particles, eightfold way of defining “strangeness” for the quark. Formal introduction of the elementary particle “quark” concept, the building blocks for protons and neutrons. The “quark” name is based on an expression in the book <i>Finnegans Wake</i> by James Joyce.
1964	Charles Hard Townes (1915–2015), Nikolay Gennadiyevich Basov [Николай Геннадиевич Басов] (1922–2001) and Aleksandr Mikhailovich Prokhorov [Александр Михайлович Прόхоров] (1916–2002)	Quantum electronics.
1970	Sheldon Lee Glashow (1932–), John Iliopoulos (1940–), and Luciano Maiani (1941–)	Introduction of the charm quark.
1974	Burton Richter (1931–) and Samuel Chao Chung Ting [Chinese: 丁肇中] (1936–)	Description of charm for the quark.
1975	Martin Lewis Perl (1927–2014)	Discovery of the tau lepton.
1977	Leon Max Ledderman (1922–)	Discovery of the “beauty” and “bottom” designation for quarks.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1978		Discovery of the “gluon” with the assistance of the PLUTO, the first electromagnetic superconductive solenoid located in Hamburg, Germany.
1983	Collider Detector at Fermilab	World’s first and at the time highest-energy particle accelerator, colliding antiprotons and protons propelled to center-of-mass energy reaching 2 TeV.
1986	Karl Alexander Müller (1927–) and Johannes Georg Bednorz (1950–)	High-temperature superconductivity.
1991	Sumio Iijima [飯島 澄男] (1939–)	Discovery of carbon nanotube.
1992	Kenneth Kin Man Kwong ()	Introduction of “functional MRI.” In 2013 the sugar consumption was measured in cancer cells with respect to normal cells for diagnostic verification.
1995	Wolfgang Ketterle (1957–), Eric Allin Cornell (1961–), and Carl Edwin Wieman (1951–)	Experimental verification of Bose–Einstein condensation.
1997	Sir Konstantin Sergeevich Novoselov (1974–) and Sir Andre Konstantin Geim (1958–)	Introduction of nanoscience; in particular the properties of graphene.

Thermodynamics

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
3300 BC–1000 BC	Bronze Age	Smelting and forging of soft metals using low heat: copper, tin, and gold. This age also introduces the written documentation.
1000 BC–700 AD	Iron Age	Higher heat requirements and more detailed tool manufacturing, introducing scientific and engineering challenges. Historical tracking of processes and developments and philosophies. Introduction of complicated mechanisms and requiring detailed analytical thinking.
500 BC	Heraclitus of Ephesus [Heraclitus: Ἡράκλειτος] (535 BC–475 BC)	Introduction of the concept of “flux”; referring to the flow of energy as well as media. One of the first reference to basic thermodynamic principles.
350 BC	Aristotle (384 BC–322 BC)	The word “energy” has the Greek origin “ <i>enérgeia</i> ” [Greek: ἐνέργεια], which was documented by Aristotle, “ <i>enérgeia</i> ” does not translation verbatim into English, the meaning resembles: “performing work.”

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
40 BC	Marcus Vitruvius Pollio [Vitruvius] (ca. 80 BC–10 BC)	Architectural designs that harness the solar energy.
62	Hero of Alexandria [ῥων ὁ Ἀλεξανδρεὺς], (10–70)	Mathematician, physicist, and mechanical engineer who also taught pneumatics. A set of two books, <i>The Pneumatica</i> , describes mechanical devices worked by air, steam, or water pressure. Also known as Heron of Alexandria. He invented a steam-powered engine called the “Æolipile,” relying on the heat exchange and mechanical conversion; fundamental thermodynamic concepts in practical application.
1500	Leonardo da Vinci (1452–1519)	The preverbal “Renaissance man,” involved in all aspects of cultural evolution, science, engineering, politics, and art.
1543	Nicolaus Copernicus (1473–1543); Alias of Niclas Koppernigk	Introduction of the heliocentric model for the earth, sun, and other planets. This follows the statement by the astronomer from Greece: Aristarchus of Samos (ca. 310–ca. 230 BC), made more than 1700 years prior. The scientific observations made by Copernicus were validated by Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).
1590	Francis Bacon, 1st Viscount of St. Alban (1561–1626)	Statement referring to motion being the essence of heat.
ca. 1600	William Gilbert (1544–1603)	
ca. 1600	Galileo Galilei (1564–1642)	Using a “thermoscope” Galileo Galilei was able to derive that fact that energy is exchanges during the flow of air and as such assign a scale of “heat” to the sensation: hotness vs. coldness. This principle can be traced back to Hero of Alexandria (10–70).
1614	René Descartes (1596–1650)	Introduction to vortex motion. Introduction of the concept of general corpuscular motion, extending from small (maybe referring to the undefined atom), to planetary orbits.
1660	Robert Boyle (1627–1691)	Gas laws, definition of the behavior or gases and phenomenological thermodynamic observations.
1673	Christiaan Huygens (1629–1695)	Construction of a “combustion engine” powered by gun powder. Huygens introduced several concept of mechanical engineering and described the mechanism of shock waves. The mathematical efforts of Christiaan Huygens in probability theory were far advanced and he collaborated with the mathematician Pierre de Fermat (1601–1665) from France.
1676		
1679	Denis Papin (1647–ca. 1712)	Pressure with inherent thermodynamic and mechanical impacts.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1680	Robert Hooke (1635–1703)	Force applied by a compressed spring and associated stored potential energy, which is exerted as kinetic energy upon release of the spring.
ca. 1687	Sir Isaac Newton (1643–1727)	
1687	Guillaume Amontons (1663–1705)	Innovations on hygrometer, thermometer, and barometer. Speculation about the existence of a low enough temperature where all atomic, respectively, molecular motion of a gas will cease, an “absolute zero” temperature, in reference to his experimentation with gases and based on the work of Joseph Louis Gay-Lussac (1778–1850). Additional work of Guillaume Amontons in 1699 describes friction in great detail, later verified by Charles-Augustin de Coulomb (1736–1806) in 1781.
1698	Thomas Savery (1650–1715)	Construction of the basic steam engine; using information obtained by Denis Papin (1647–c. 1712).
1712	Thomas Newcomen (1664–1729)	Construction of a “atmospheric” steam engine.
1724	Herman Boerhaave (1668–1738)	Description of phase changes for media and the associated exchange of energy.
1732	Anders Celsius (1701–1744)	Thermometer-scale calibration based on pure water phases.
1735	Daniel Gabriel Fahrenheit (1686–1736)	Temperature scale in Fahrenheit based on body temperature and saltwater phases.
1738	Daniel Bernoulli (1700–1782)	Hydrodynamics, vibrations, and kinetic theory. Definition of the fundamental frequency and higher harmonics, with supporting elaborate mathematical analysis (solutions to differential equations) in his publication <i>Hydrodynamica</i> .
1752	Benjamin Franklin (1706–1790)	Kite experiment and the documentation of “electric current” with associated electric energy content, most visible in the destructive power of lightning bolts.
1783	Antoine Laurent de Lavoisier (1743–1794)	Introduction of the “caloric theory,” “substance of heat.” Lavoisier constructed the first known calorimeter and measured the heat exchange resulting from a chemical reaction.
1757–1769	James Watt (1736–1819)	Modern steam engine design and operation with theoretical description of operation.
1762	Joseph Black (1728–1799)	Realization of the concept of latent heat; observation that ice is melting (phase change to liquid) without a change in temperature.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1769	Nicolas-Joseph Cugnot (1725–1804)	First operational steam powered automobile, the predecessor to the internal combustion automobile.
1777	Carl Wilhelm Scheele (1742–1786)	Recognized heat transfer as the result of radiation (infrared light) to be a different exchange mechanism than convection and conduction.
1781	Charles-Augustin de Coulomb (1736–1806)	Definition of the electric field related to electric charge. The electric charge itself was still an elusive concept in those days.
1783	Antoine Laurent de Lavoisier (1743–1794)	Discovery of oxygen and the chemical impact.
1783	Joseph-Michel Montgolfier (1740–1810) and Jacques-Étienne Montgolfier (1745–1799)	Hot-air balloon; buoyancy.
1785	Jacques Alexandre César Charles (1746–1823)	Charles's law, expansion of gases.
1791	Pierre Prévost (1764–1823)	Experimentally verifies that all bodies radiate heat, regardless of their temperature. Precursor to Planck's law and Wien's law.
1798	Count Rumford (1753–1814), Benjamin Thompson	Quantitative analysis of the conversion of heat into work by means of his cannon-boring experimentation. This relates kinetic energy to heat and discredits the caloric theory.
1799	Sir Humphry Davy, 1st Baronet (1778–1829)	Experimental quantification of the conversion of work (friction) into heat using ice blocks that were rubbed on a surface and caused a phase change: liquification.
1802	Joseph Louis Gay-Lussac (1778–1850)	Ideal gas law; building on the work by Robert Boyle (1627–1691), more than a century earlier.
1824	Nicolas Léonard Sadi Carnot (1796–1832)	Thesis publication: "Reflections on the Motive Power of Fire," leading to the refrigerator for general public in 1842. Carnot introduced the cyclic process, which could be built into a cyclic machine, operating between two heat reservoirs, using the temperature of the reservoir as the parameter that influences the process, not necessarily the medium that is used in the system.
1827	Benoît Fourneyron (1802–1867)	First water turbine.
1841	Julius Robert von Mayer (1814–1878)	First attempt to define the laws of conservation, but was unsuccessful. Even though Julius Robert von Mayer lacked the mathematical skills to support his hypothesis he is still considered to be one of the founding fathers of thermodynamics.

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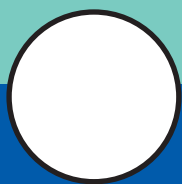
CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1843	James Prescott Joule (1818–1889)	Quantitative experimental data collection and theoretical description of principal thermodynamic concepts.
1843–1848	James Prescott Joule (1818–1889)	Empirical verification of the first law of thermodynamics; equivalence of heat and work. This was later rewarded by assigning the heat quantity in unit Joule (J). Publication in 1851: “Remarks on the heat and the constitution of elastic fluids.”
1847	Hermann Ludwig Ferdinand von Helmholtz (1821–1894)	Formulation of the principles of conservation of energy.
1848	William Thomson, 1st Baron Kelvin (i.e., Lord Kelvin) (1824–1907)	Absolute temperature scale: Kelvin.
1850	Rudolf Julius Emanuel Clausius (1822–1888)	Recognition of two basic principles (later introduced by means of the first and second law of thermodynamics: energy is constant and entropy tends toward a maximum). Clausius introduced the parameter U , representing the internal energy. Publication of book: <i>On the Motive Power of Heat, and on the Laws Which Can Be Deduced From It for the Theory of Heat</i> . According to Josiah Willard Gibbs (1839–1903) Clausius was one of the founding fathers of thermodynamics in the principle manner we currently still use. Clausius introduced what is now regarded the second law of thermodynamics in 1865 (referred to by William John Macquorn Rankine (1820–1872) as the “thermodynamic function”), as part of any natural thermodynamic process, the sum of the entropies of the participating systems will increase.
1852	James Prescott Joule (1818–1889) and William Thomson, 1st Baron Kelvin {Lord Kelvin} (1824–1907)	Joule–Thomson effect: rapidly expanding gas leads to a reduction in the temperature of the gas, even offering the potential for a phase change to solid, or liquid. Sometimes also found as the Joule–Kelvin effect.
1859	William John Macquorn Rankine (1820–1872)	Publication of the book <i>A Manual of the Steam Engine and Other Prime Movers</i> , chapter titled “Principles of Thermodynamics,” introducing the concept of the “thermodynamic function” later recognized as entropy.
1860	James Clerk Maxwell (1831–1879)	Maxwell statistical distribution of atomic or molecular velocities for idealized gases, allowing for only brief elastic collisions. Published in 1867 as “On the dynamical theory of gases.”
1861	Augustin Mouchot (1825–1911)	Presentation of the use of solar energy as a source for personal energy consumption.

(Continued)

CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1862	Ludwig Eduard Boltzmann (1844–1906)	Refinements to the Maxwell distribution and associated entropy based on additional implementation of kinetic gas theory. This culminated in 1877 in the Maxwell–Boltzmann distribution.
1873	Josiah Willard Gibbs (1839–1903)	Thermodynamic concept describing the energy that can be released or absorbed during a chemical reaction. In 1875 Josiah Gibbs published his <i>On the Equilibrium of Heterogeneous Substances</i> , describing the thermodynamic aspects in general form describing chemical reaction and heterogeneous systems. This work included the chemical potential, a energy constituent within the Gibbs free energy.
1879	Joseph Stefan (1835–1893)	Determination that radiation has a quantity: radiance, which is proportional to the fourth power of the temperature of the system.
1893	Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928)	Black body emission: Wien's displacement law. The peak radiance emitted by a black body (spectral radiance) shifts to shorter wavelengths at higher temperatures.
1895	Wilhelm Röntgen (1845–1923)	Discovery of X-ray (Röntgen rays).
1897	Joseph John Thomson (1856–1940)	Discovery of the electron; using William Crookes's vacuum tube.
1900	Ludwig Eduard Boltzmann (1844–1906)	Boltzmann equation for statistical mechanics, introduced by Ludwig Boltzmann between 1872 and 1875, reformulated by Max Karl Ernst Ludwig Planck (1858–1947) defining the entropy of a system. For certain systems also addressed as the Gibbs entropy formula, after Josiah Willard Gibbs (1839–1903).
1906	Walther Hermann Nernst (1864–1941)	Third law of thermodynamics: "The entropy of a perfect crystal at absolute zero is exactly equal to zero," influenced by Johannes Diderik van der Waals (1837–1923).
1909	Constantin Carathéodory (1873–1950)	Theoretical discourse on thermodynamics, based on axiomatic principles, entirely mathematical in its format.
1912	Peter Joseph William Debye (1884–1966)	Increased accuracy in determination of heat capacity for a body by means of implementation of low frequency acoustics (low frequency phonons) in the analysis process.
1924	Sir John Edward Lennard-Jones (1894–1954)	Definition of the attraction between two neutral molecules or atoms: Lennard-Jones potential.

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CHRONOLOGY	NOTEWORTHY PEOPLE	EVENTS AND DISCOVERIES
1924	Satyendra Nath Bose (1894–1974) [সত্যেন্দ্র নাথ বসু] and Albert Einstein (1879–1955)	Introduction of the Bose–Einstein statistics: one of two potential manners of energy occupation for a collection of noninteracting indistinguishable particles with respect to a set of available discrete energy states, this applies to thermodynamic equilibrium only. At extreme low temperatures, these energy levels for bosons can result in a joining of states: condensation, the Bose–Einstein condensate.
1931	Georges Jean Marie Darrieus (1888–1979)	Introduction of the wind turbine.
1931	Subramanyan Chandrasekhar (1910–1995)	Relativistic thermodynamics.
1940+	Julius Robert Oppenheimer (1904–1967)	Manhattan project: fission reaction. Prominent members: Arthur Compton (1892–1962), Enrico Fermi (1901–1954), Eugene Wigner (1902–1995), and dozens more.
1948	Claude Elwood Shannon (1916–2001)	Introduction of information theory, basis is in thermodynamic principles.
1972	Stephen Hawking (1942–) and Jacob Bekenstein (1947–2015)	Thermodynamics of black holes. Specific items of interest are the following. Jacob Bekenstein: the entropy of a black hole is proportional to its surface area; Stephen Hawking: black holes may radiate particle that may lead to the “evaporation” of the black hole.



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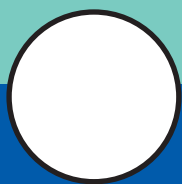
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